Investigating continental rifting in the Western US with seismic methods

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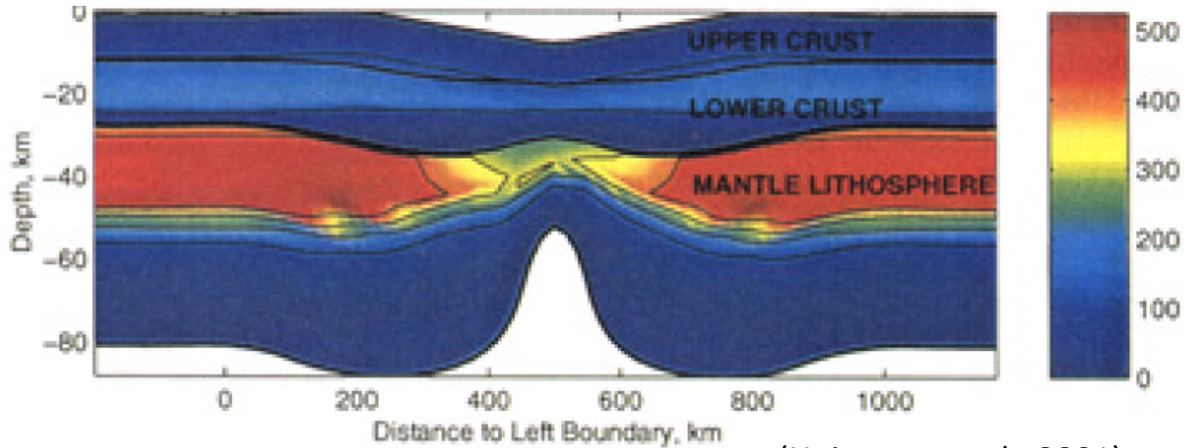
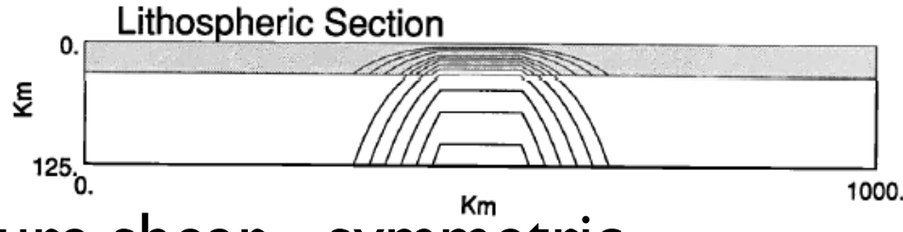
What can seismology tell us about rifting processes?

- Geometry of boundaries (Moho, LAB) constrains distribution of strain throughout lithosphere, informing on rheology and modes of deformation
- 3D/along-strike variation relates rifting to preexisting structure
- Vp/Vs ratio helps understand distribution and role of melt

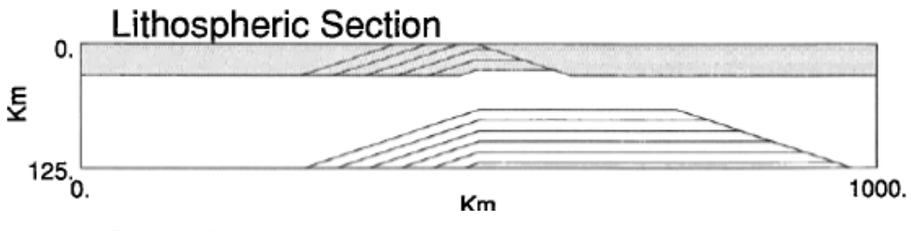
Localized strain due to upwelling



(Huismans et al., 2001)



Pure shear - symmetric



Simple shear - asymmetric

Buck 1988

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NEEDS

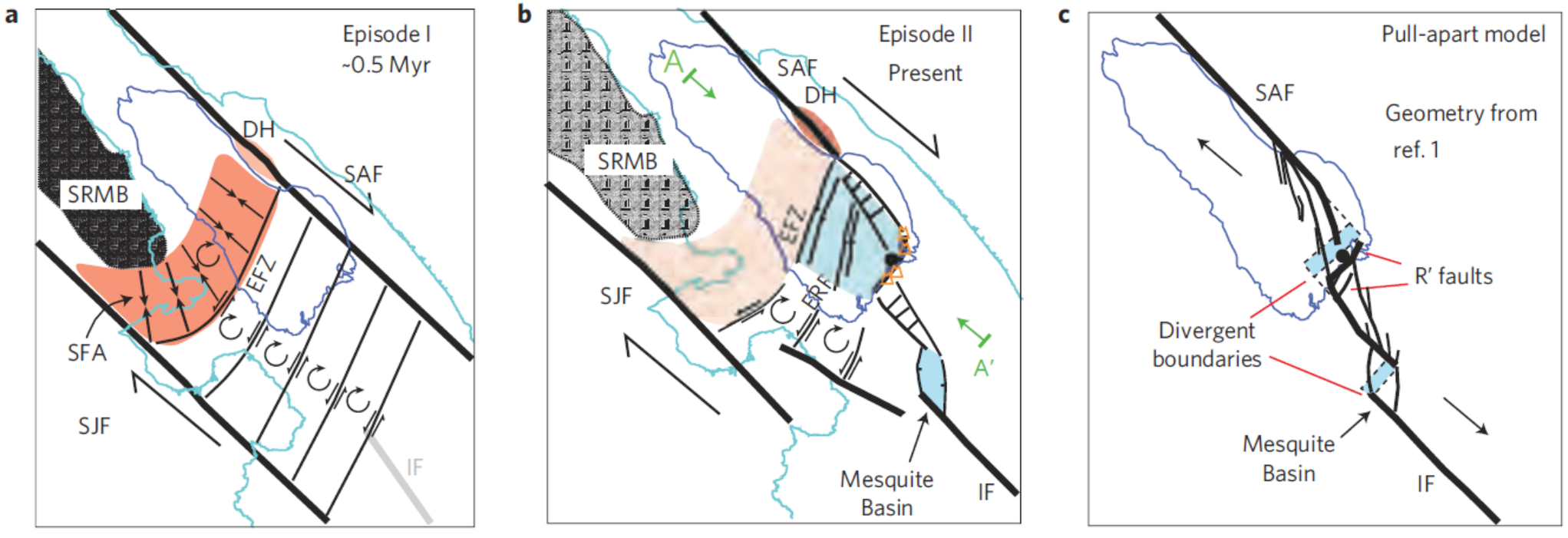
Ability to map complex, steeply dipping structure

3D formulation/ability to incorporate 3D velocities

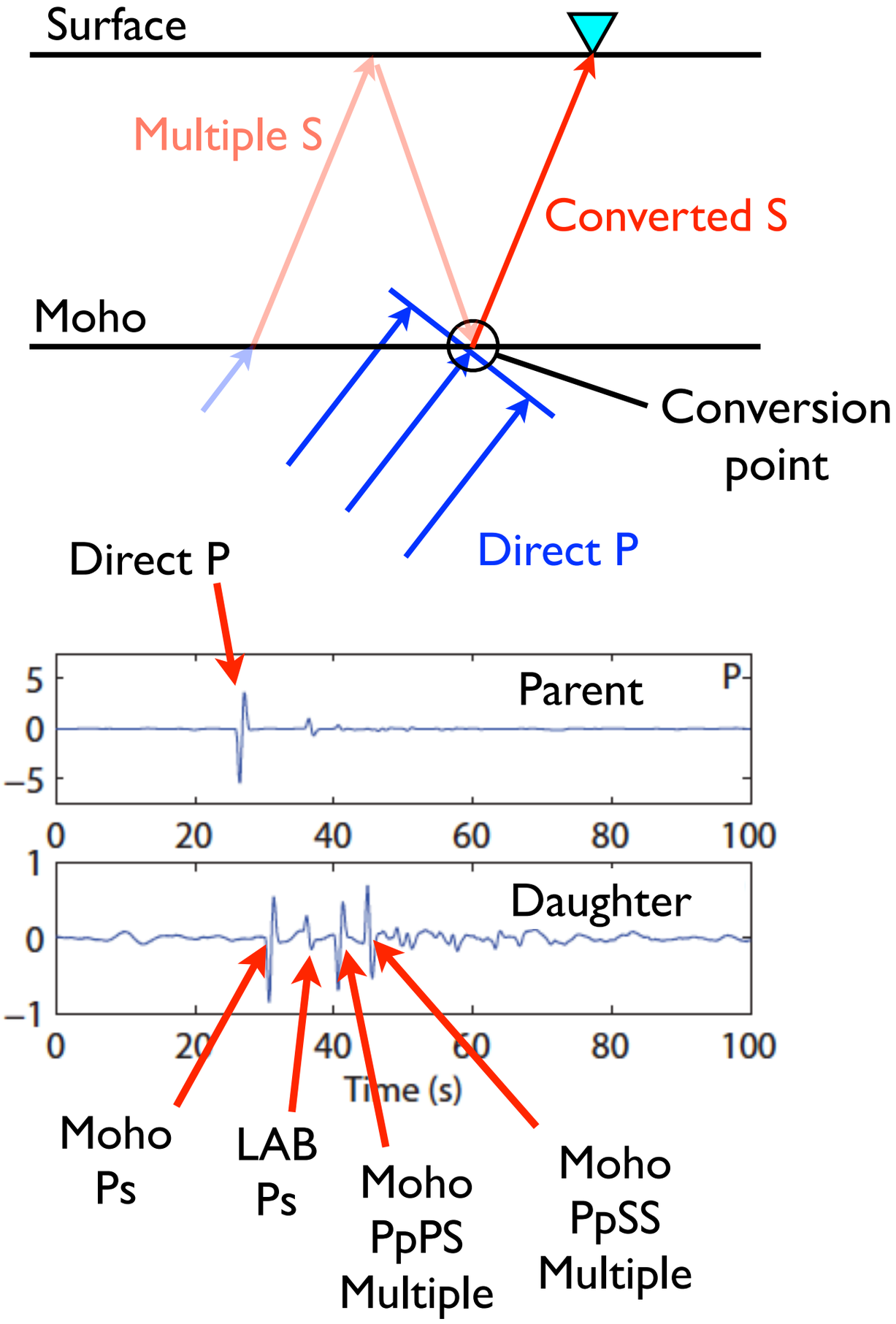
Handle tradeoff between boundary depth and smooth velocity

Continental rifting in Southern California

- At 5-6 Mya, Baja California transferred to the Pacific Plate
- Narrow mode rifting presently occurring in Salton Trough and Sea of Cortez
- Salton Trough transitioned from block rotation to pull apart basins, spreading centers



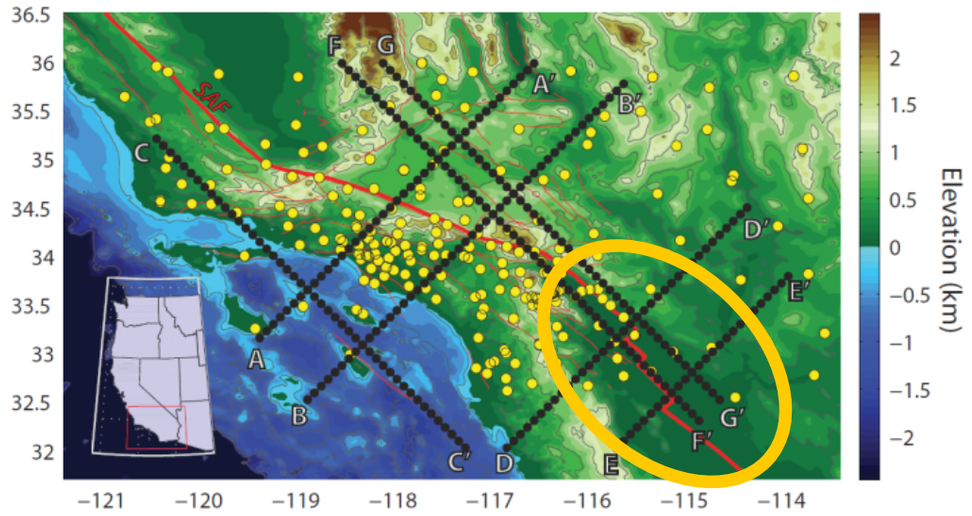
Brothers et al. 2009



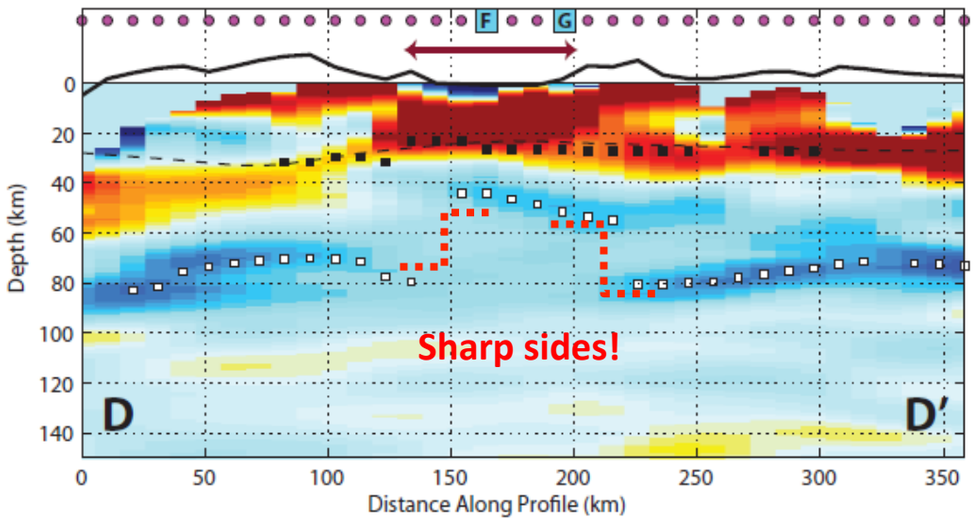
Seismic receiver function method

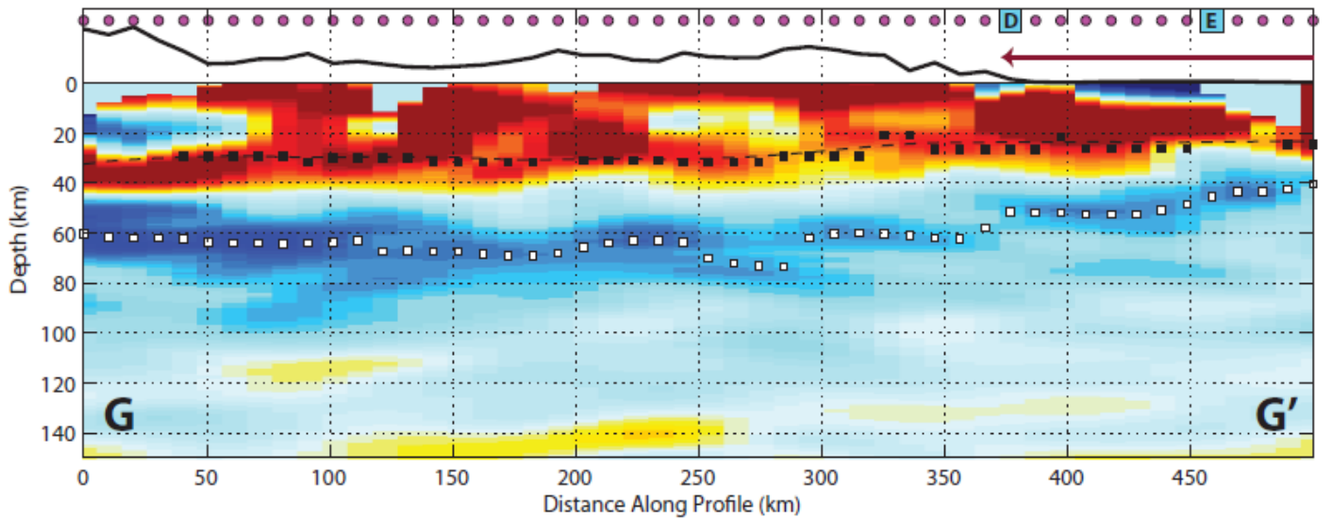
- P wave arrives from distant earthquakes
- At boundaries, some energy converted from fast P to slower S and is recorded later
- Depth to boundary calculated assuming P and S velocities and wave geometry
- Complicated by free-surface multiple reflections

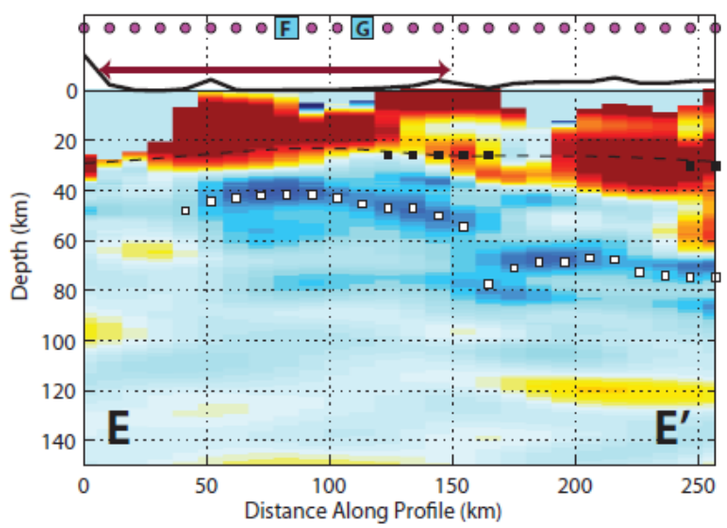
Imaging Salton Trough with Receiver Functions

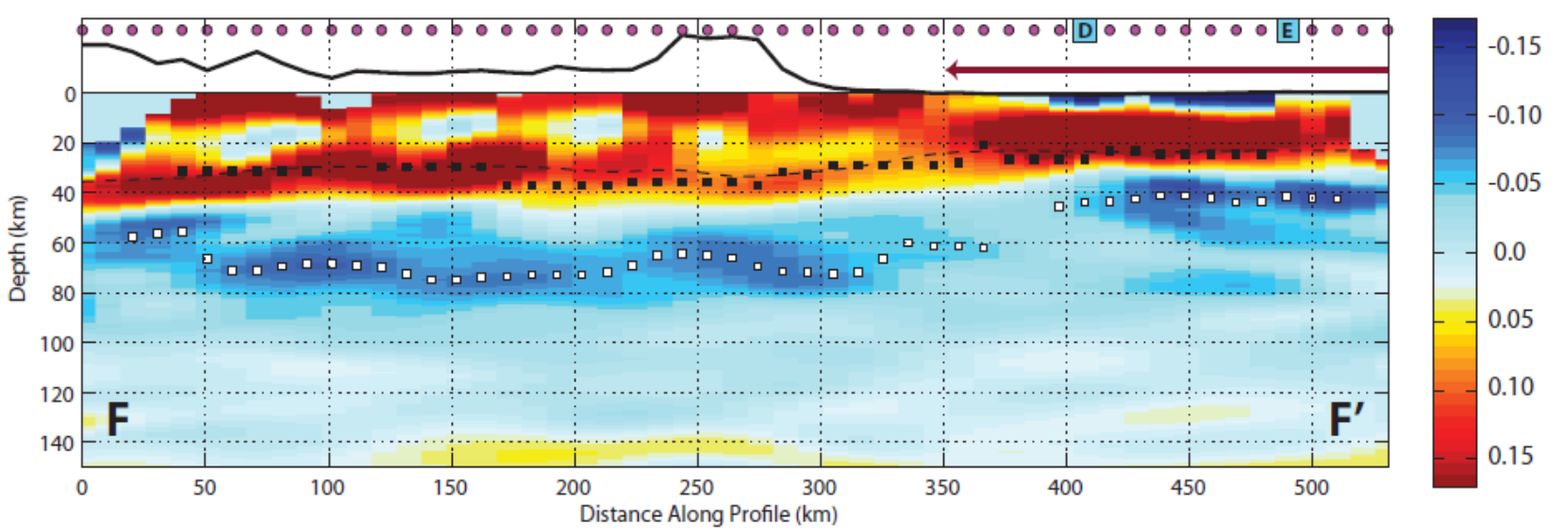


Common Conversion Point (CCP) Stacks from Lekic et al. (2011)

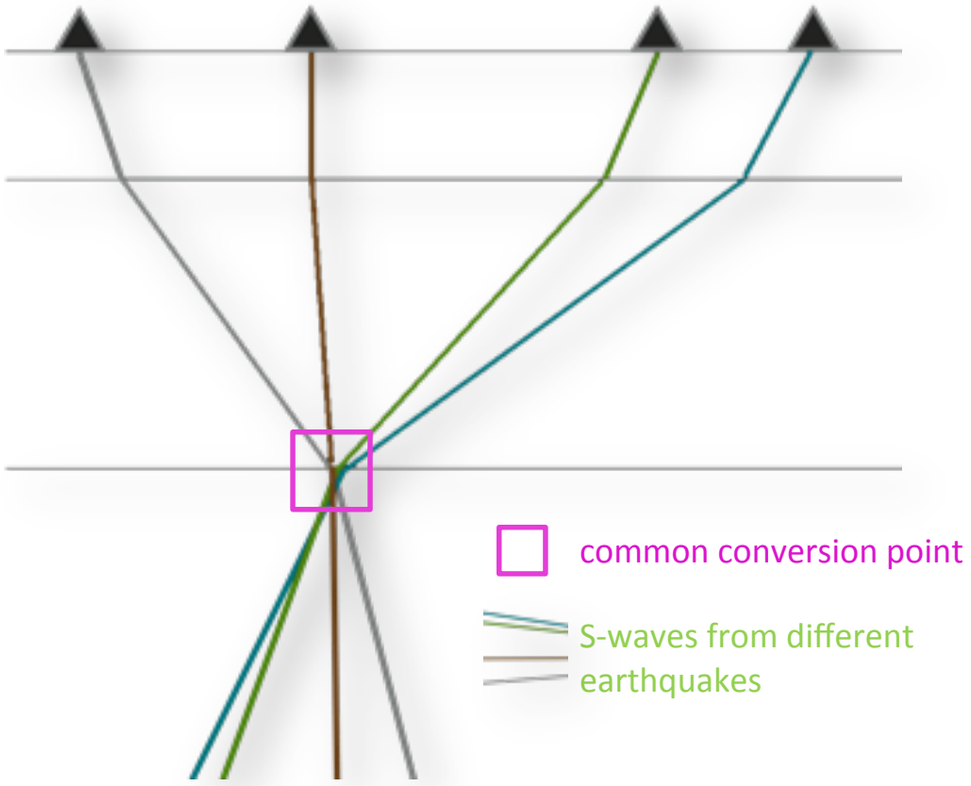


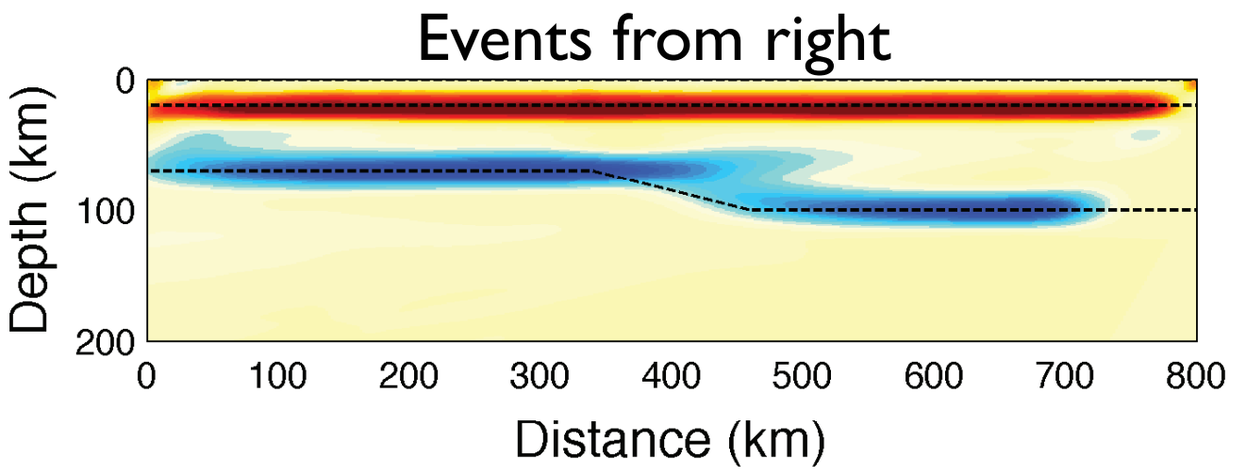


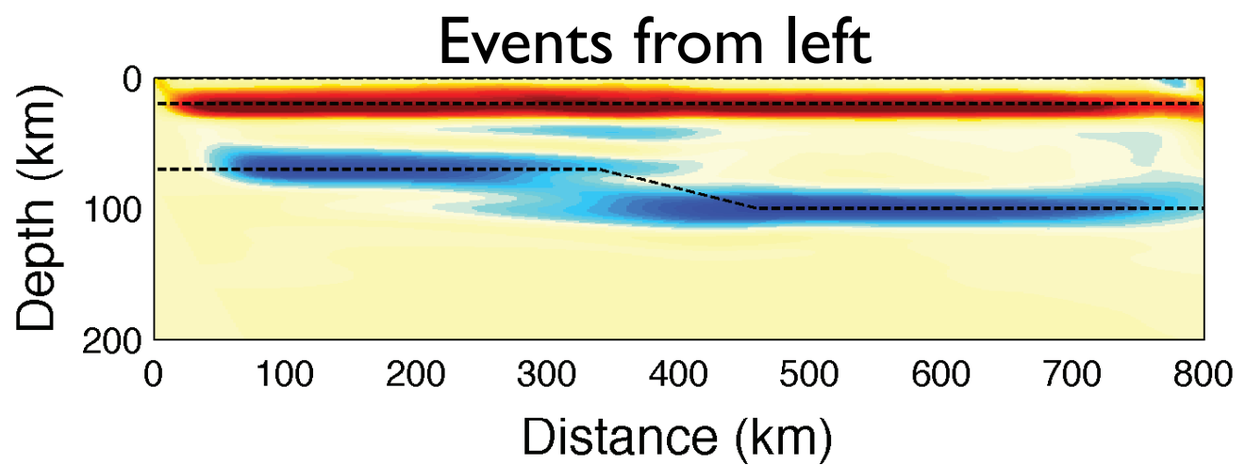




Limitations of CCP stacking

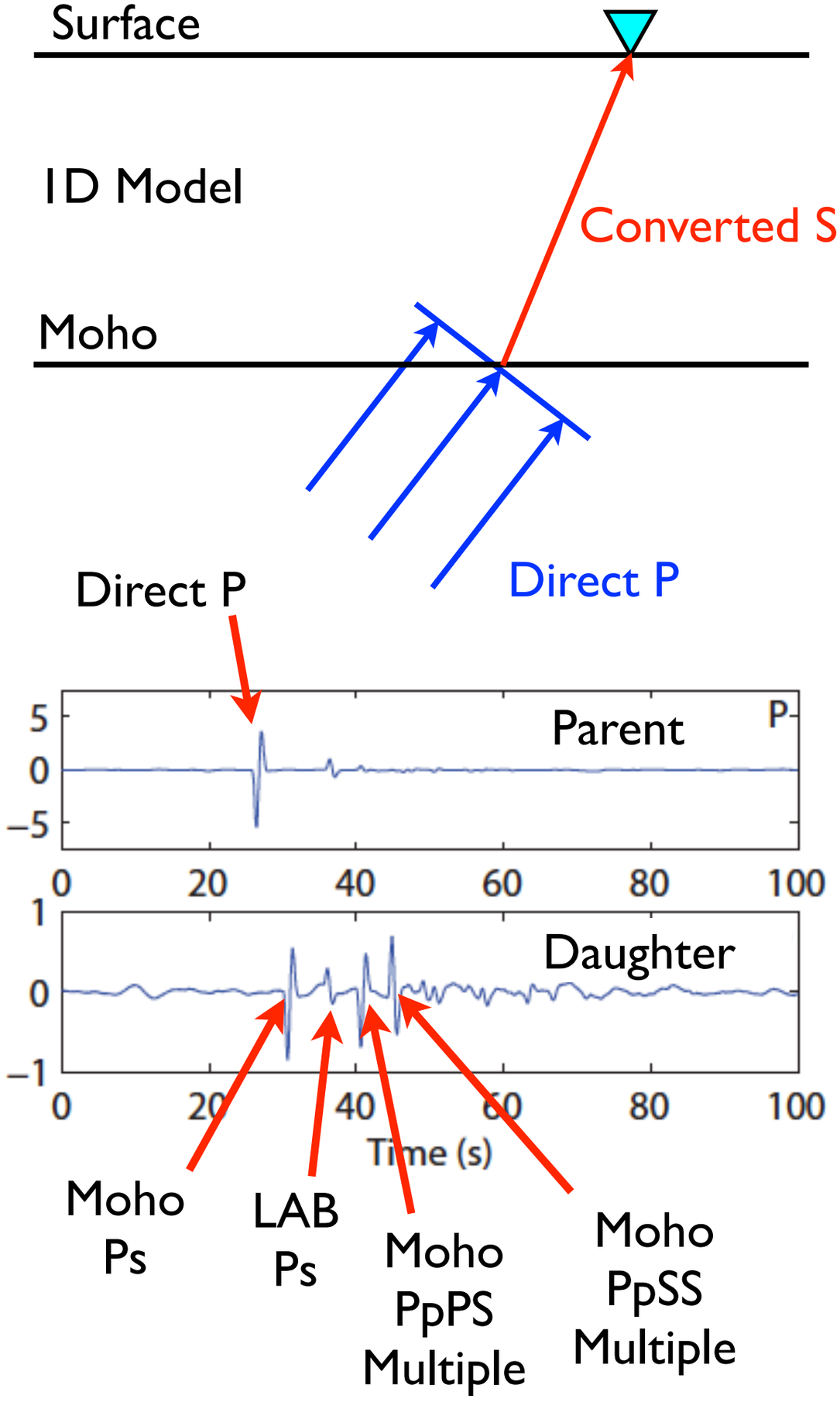






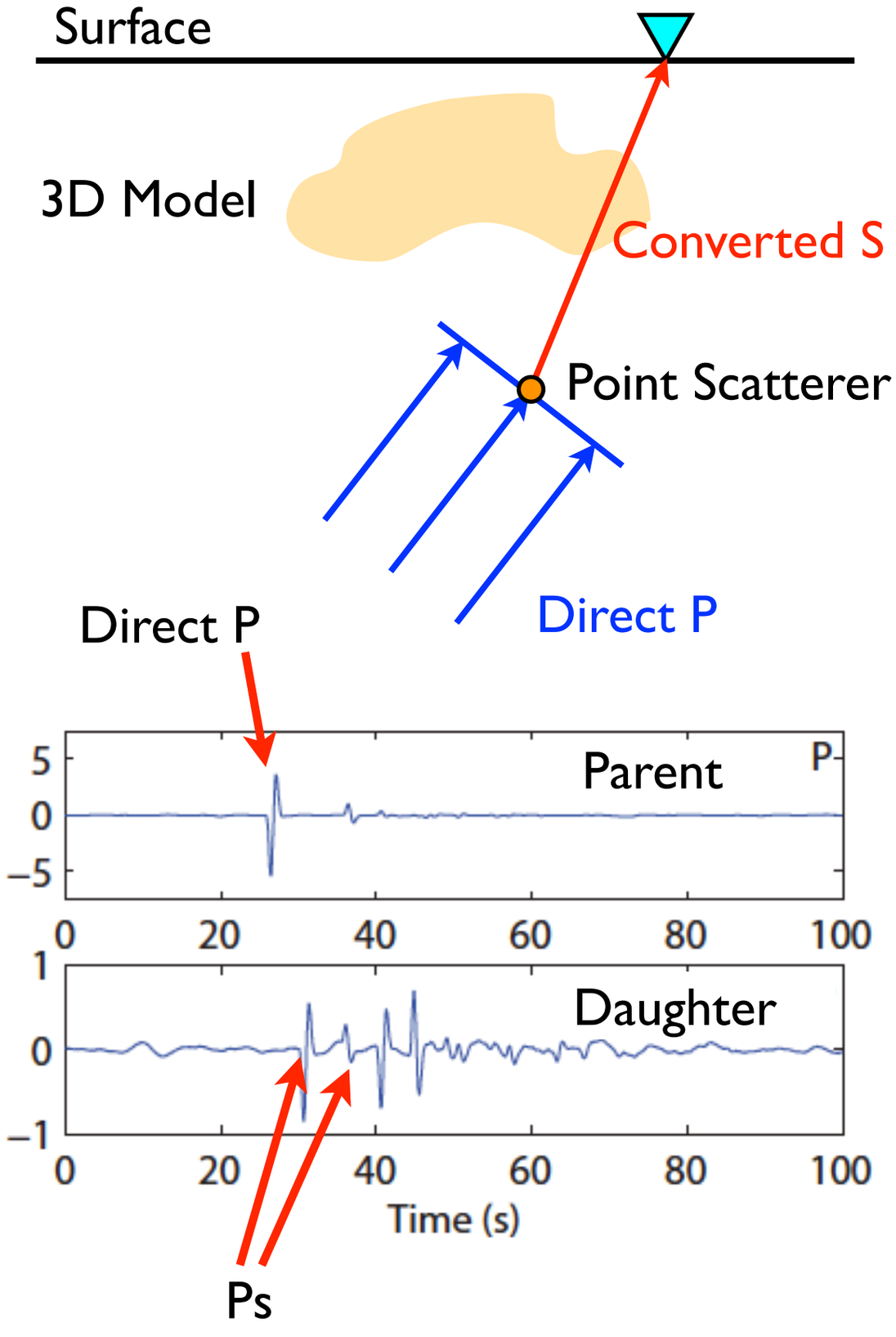
- Find conversion points assuming boundaries are flat, model is 1D
- Dip of resulting structure is inaccurate

Lekic & Fischer (in prep)



New method: 'Full' 'waveform' inversion

- Try to explain observed receiver functions
- Instead of flat layers, consider series of point scatterers
- For each point, calculate what we would record at surface if there is a jump in S velocity (time, amplitude, polarity)
- Least Squares fit to find best model of scatterers



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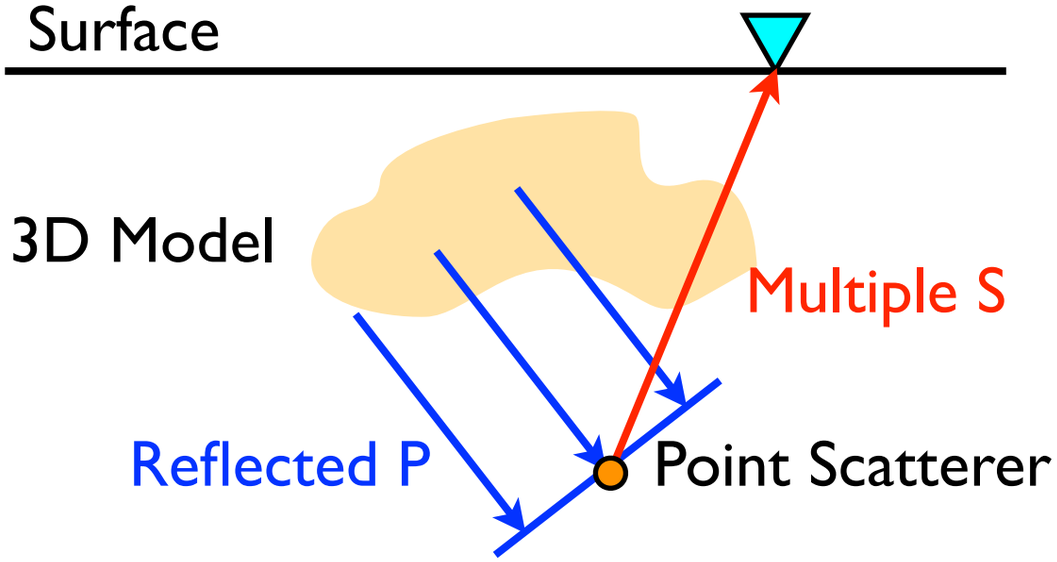

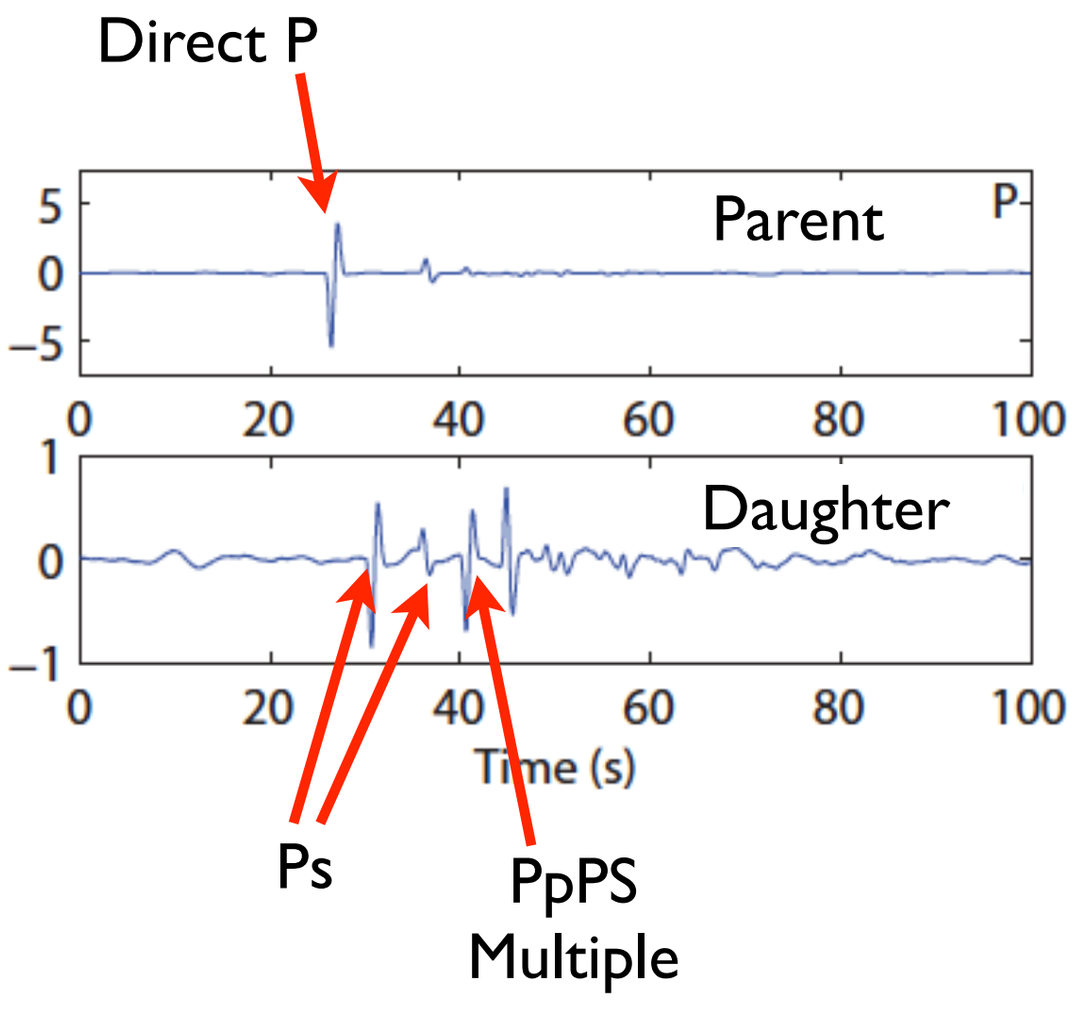

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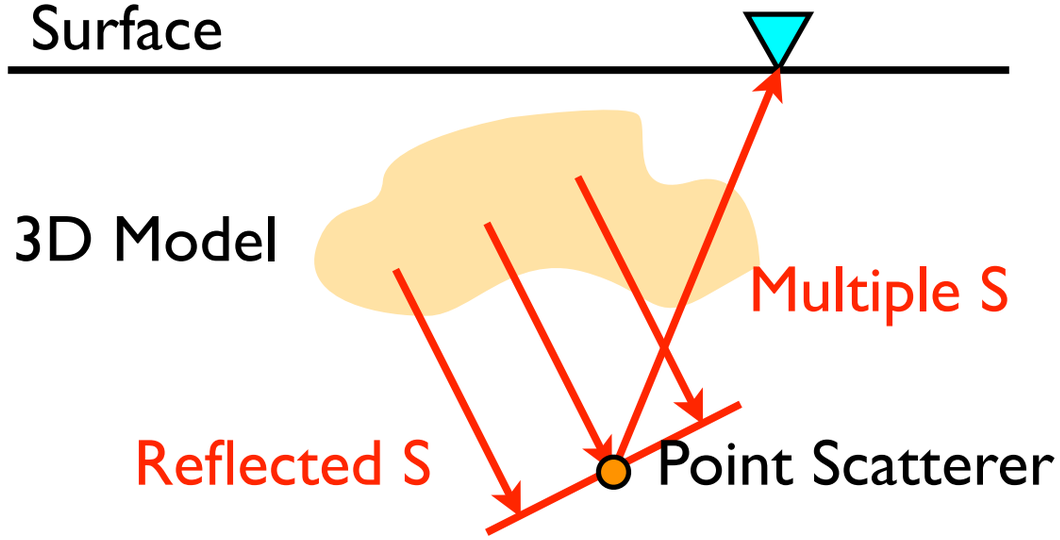

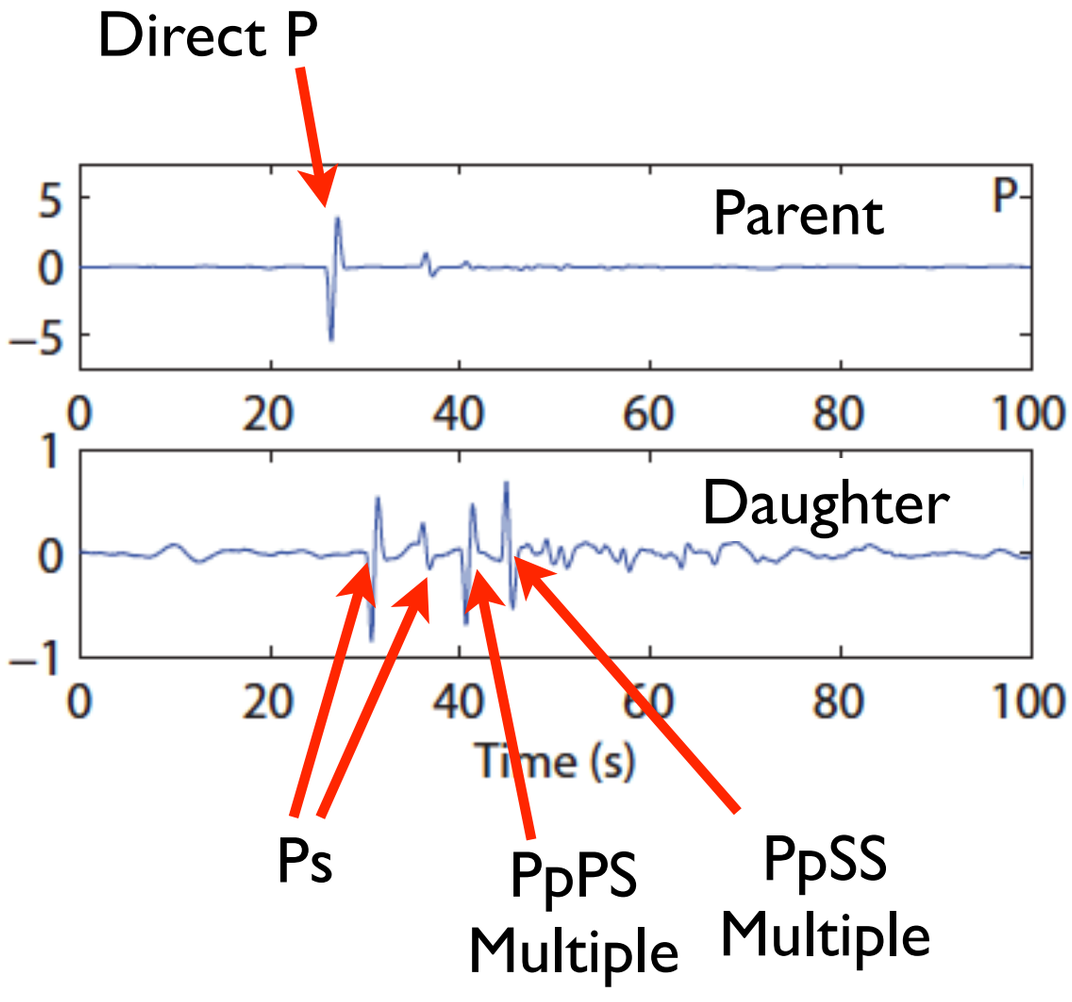

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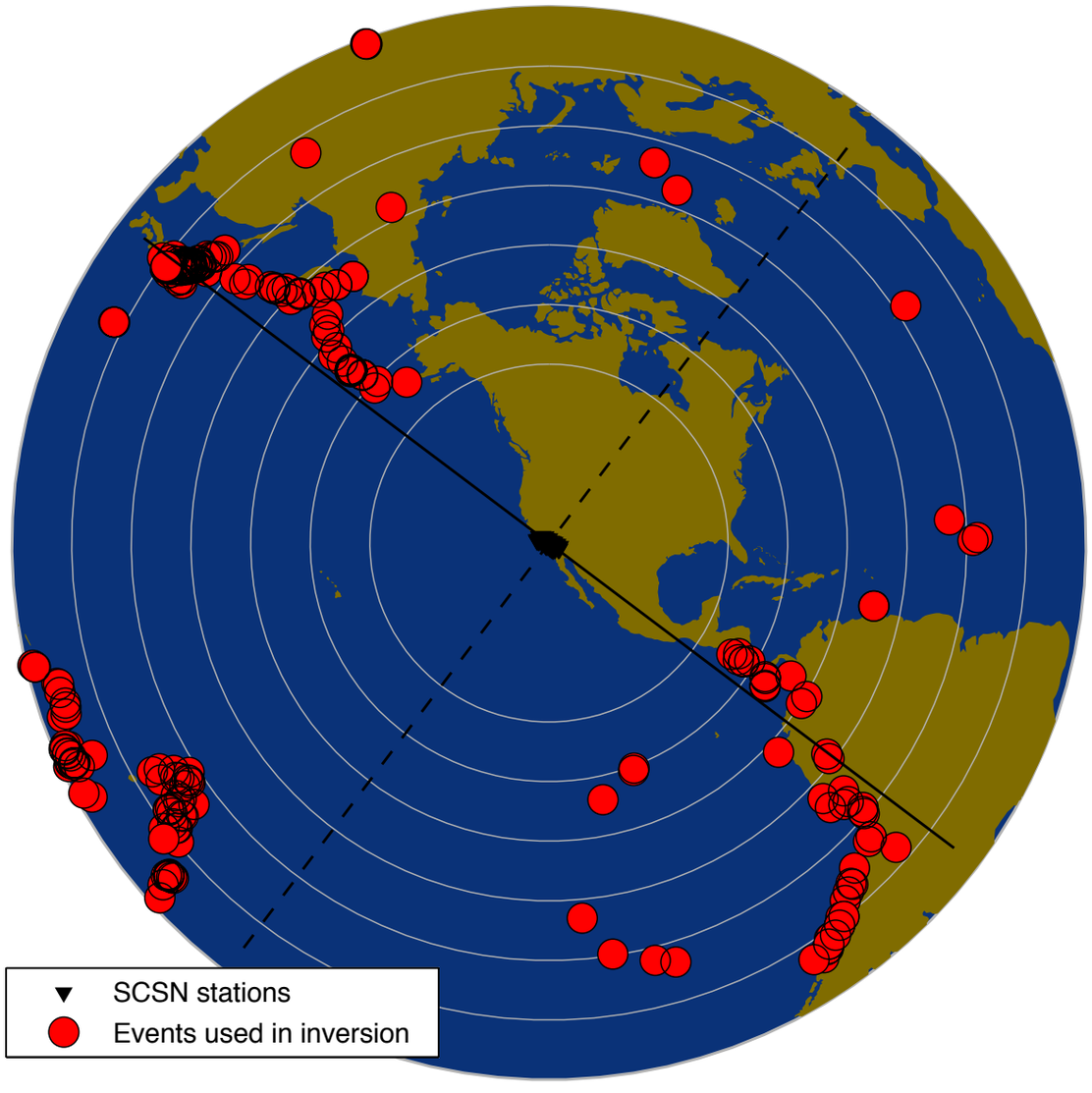
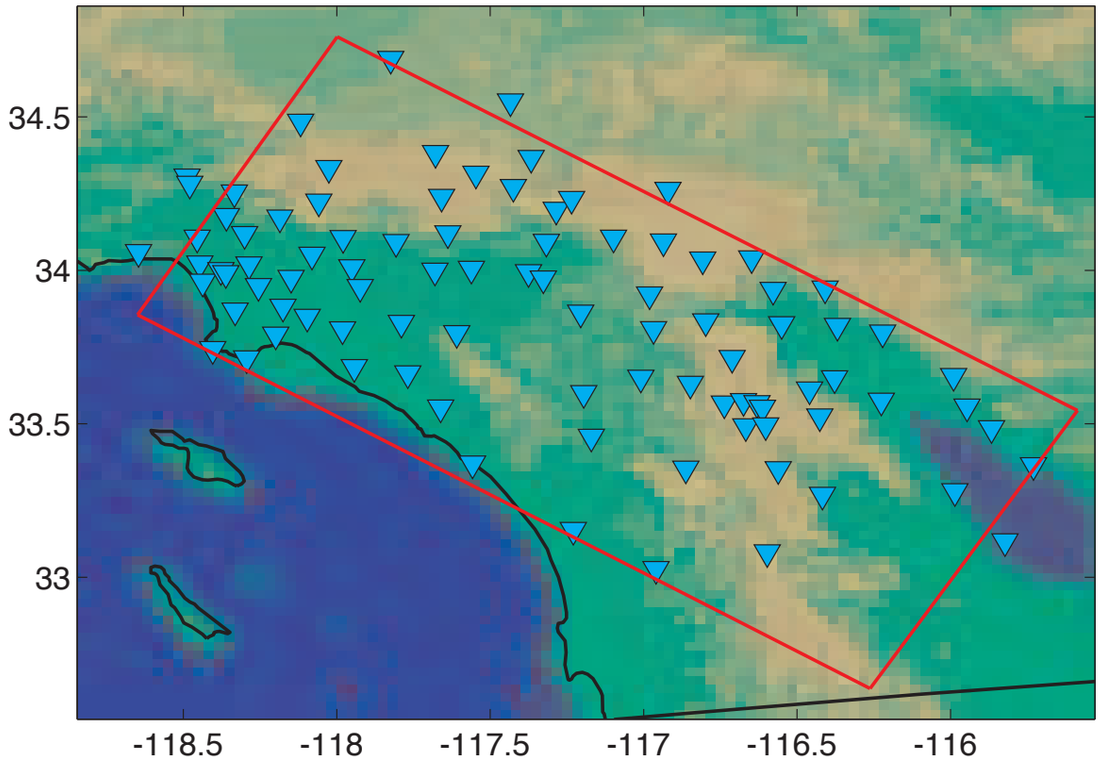
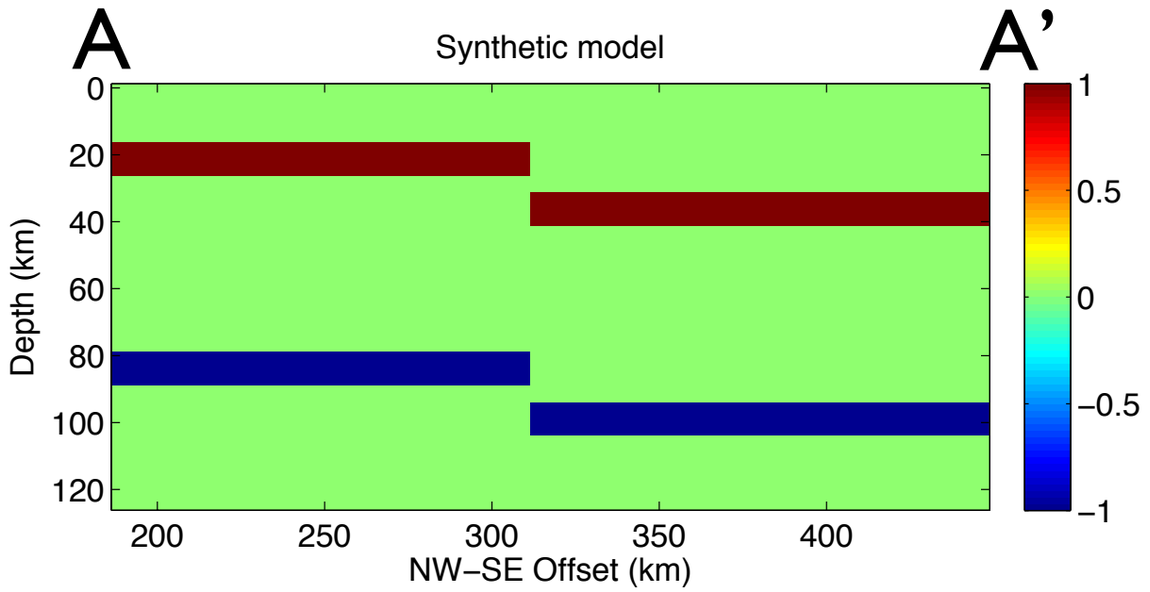
FWI with So. California Seismic Network

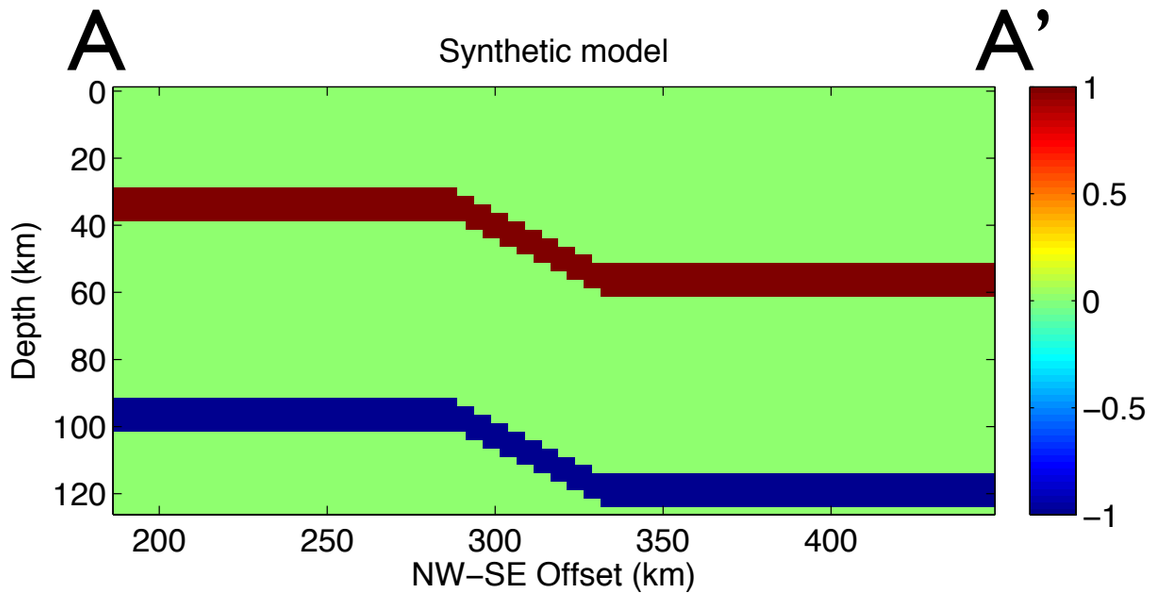
- ~200 earthquakes from 35-90°
- ~100,000 total RFs binned by azimuth and ray parameter

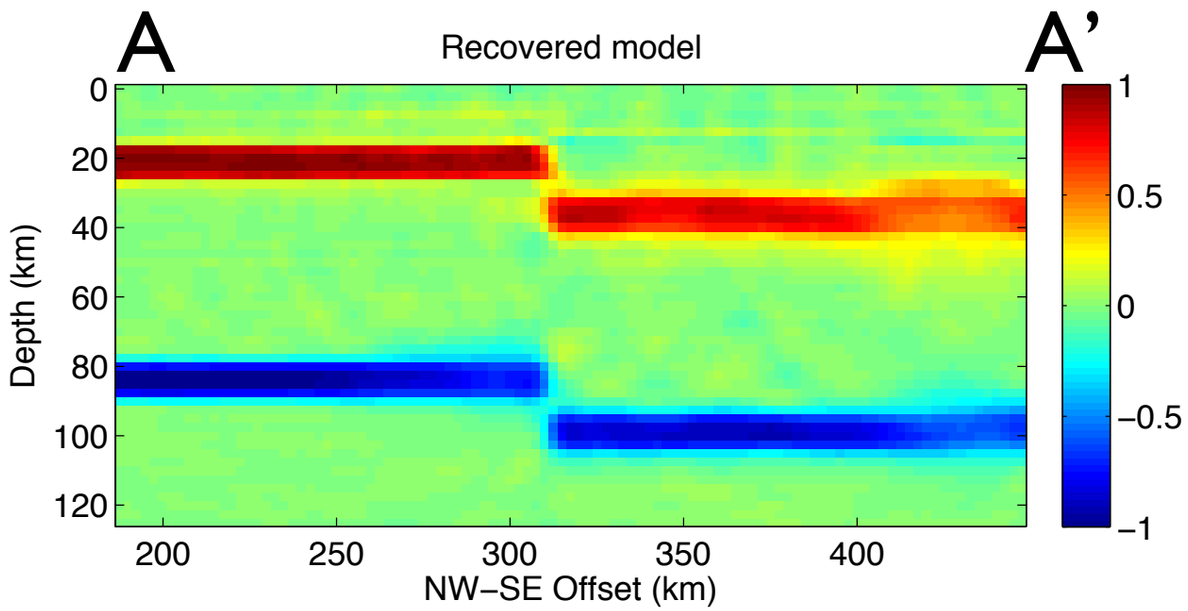


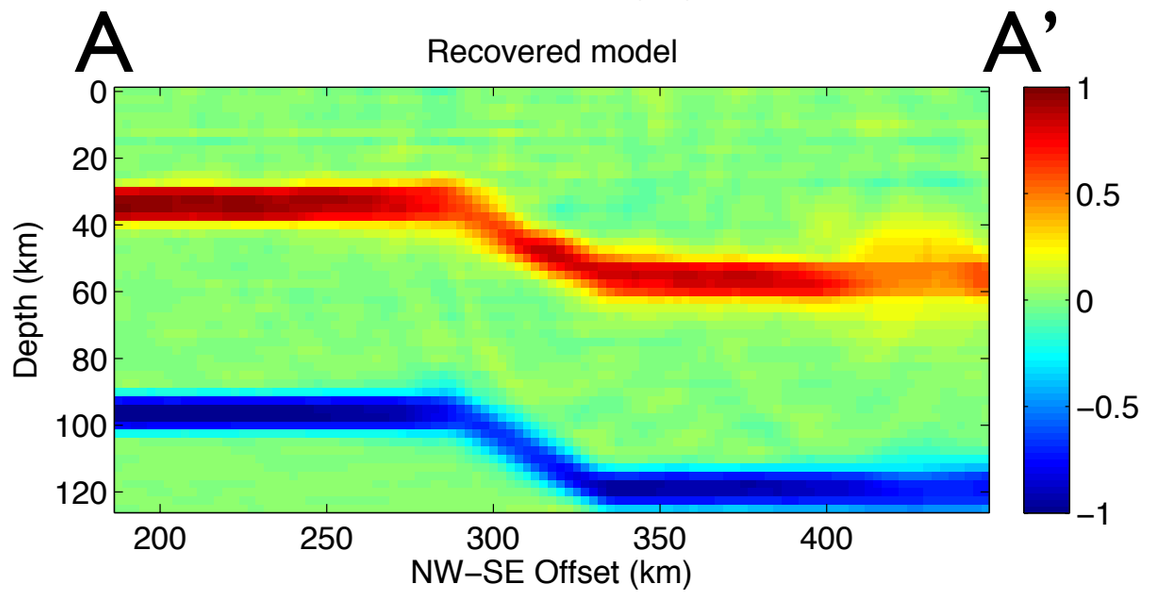


- 96 Stations from SCSN
- Paths and traveltimes calculated through regional model on 2.5km grid

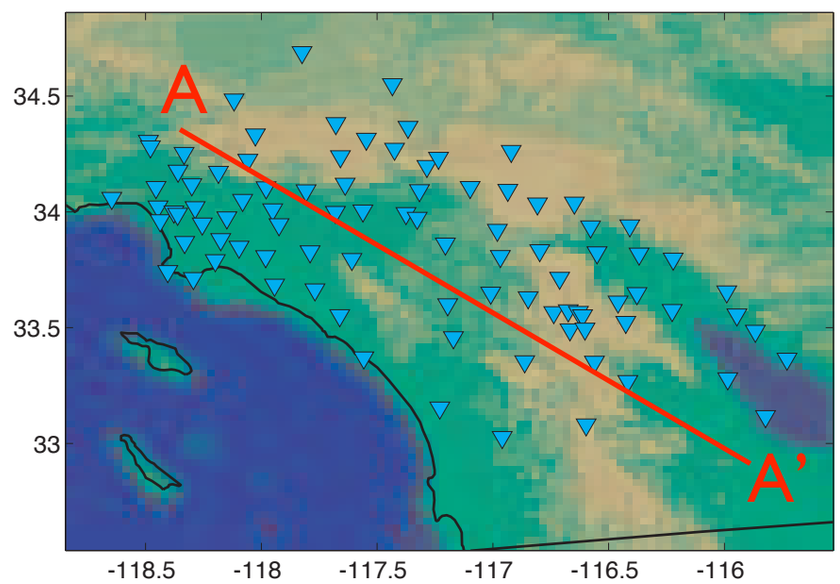




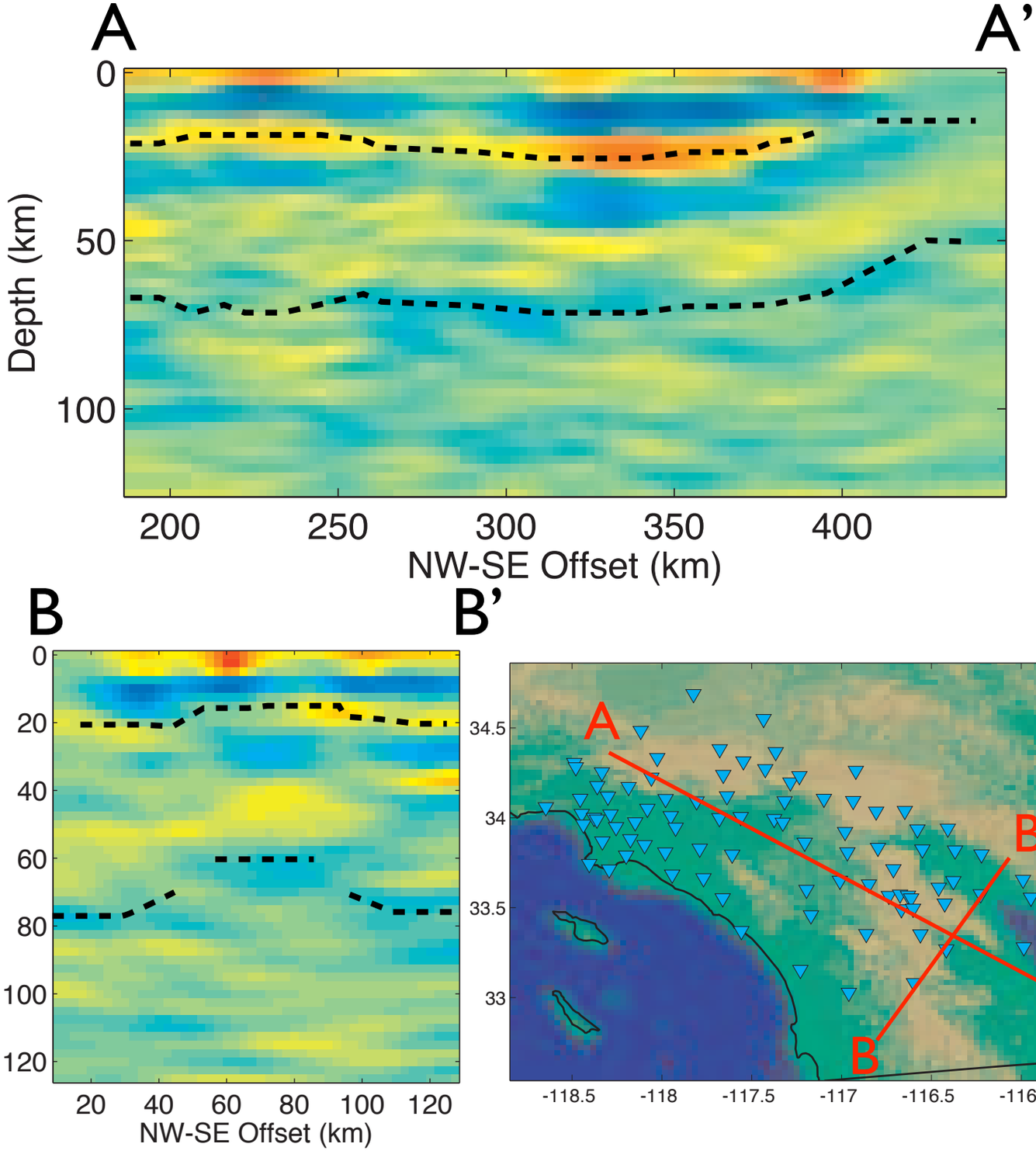




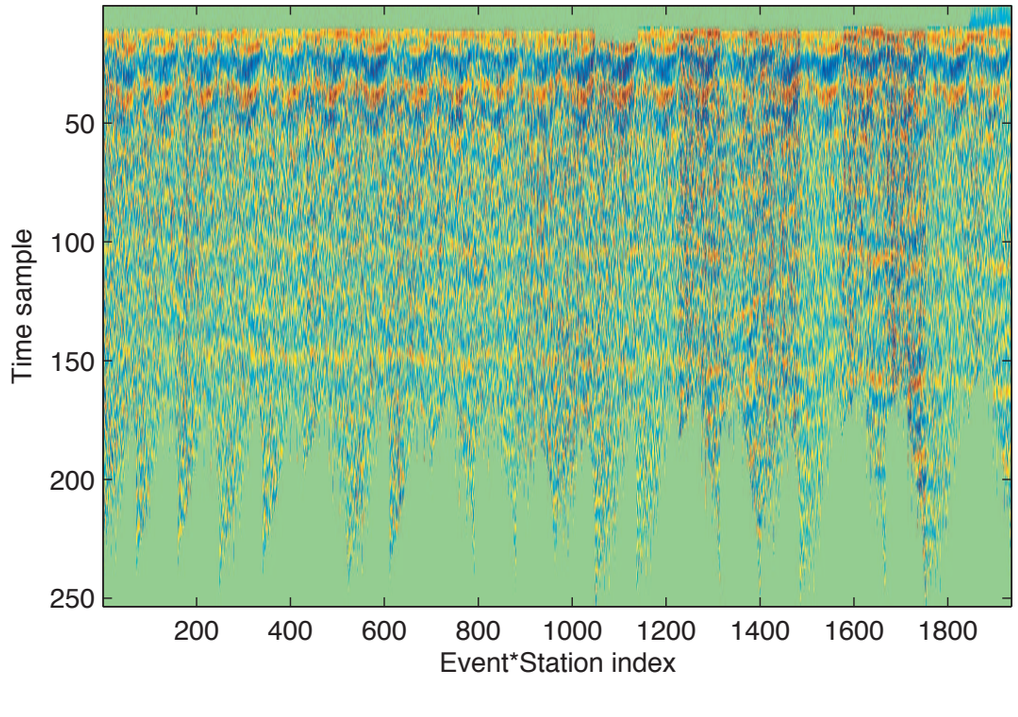
FWI synthetic tests



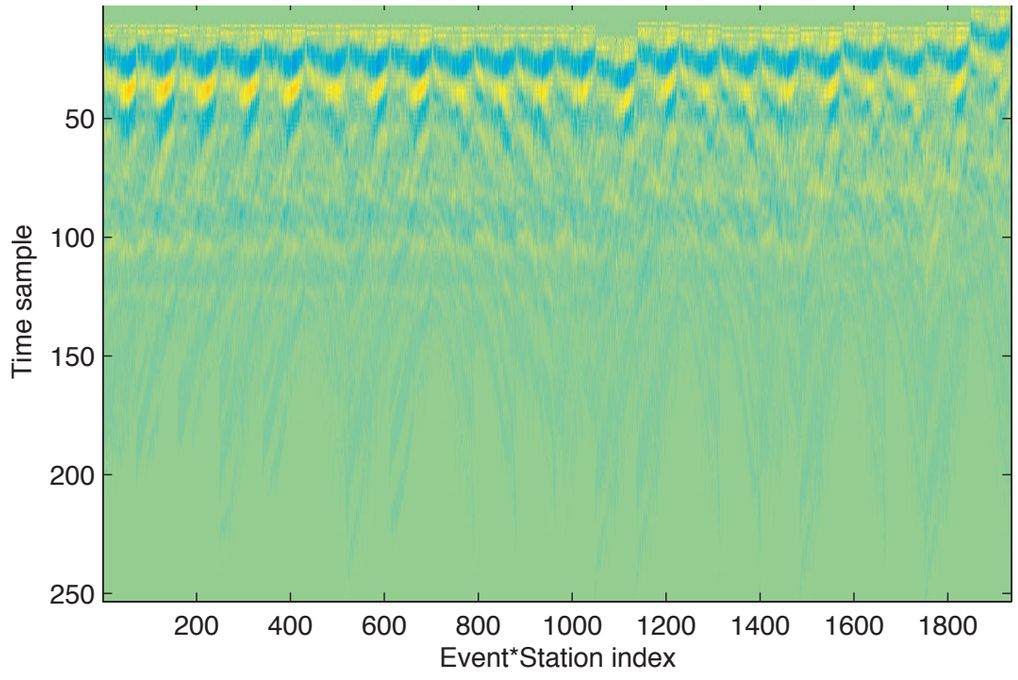
FWI results and data comparison



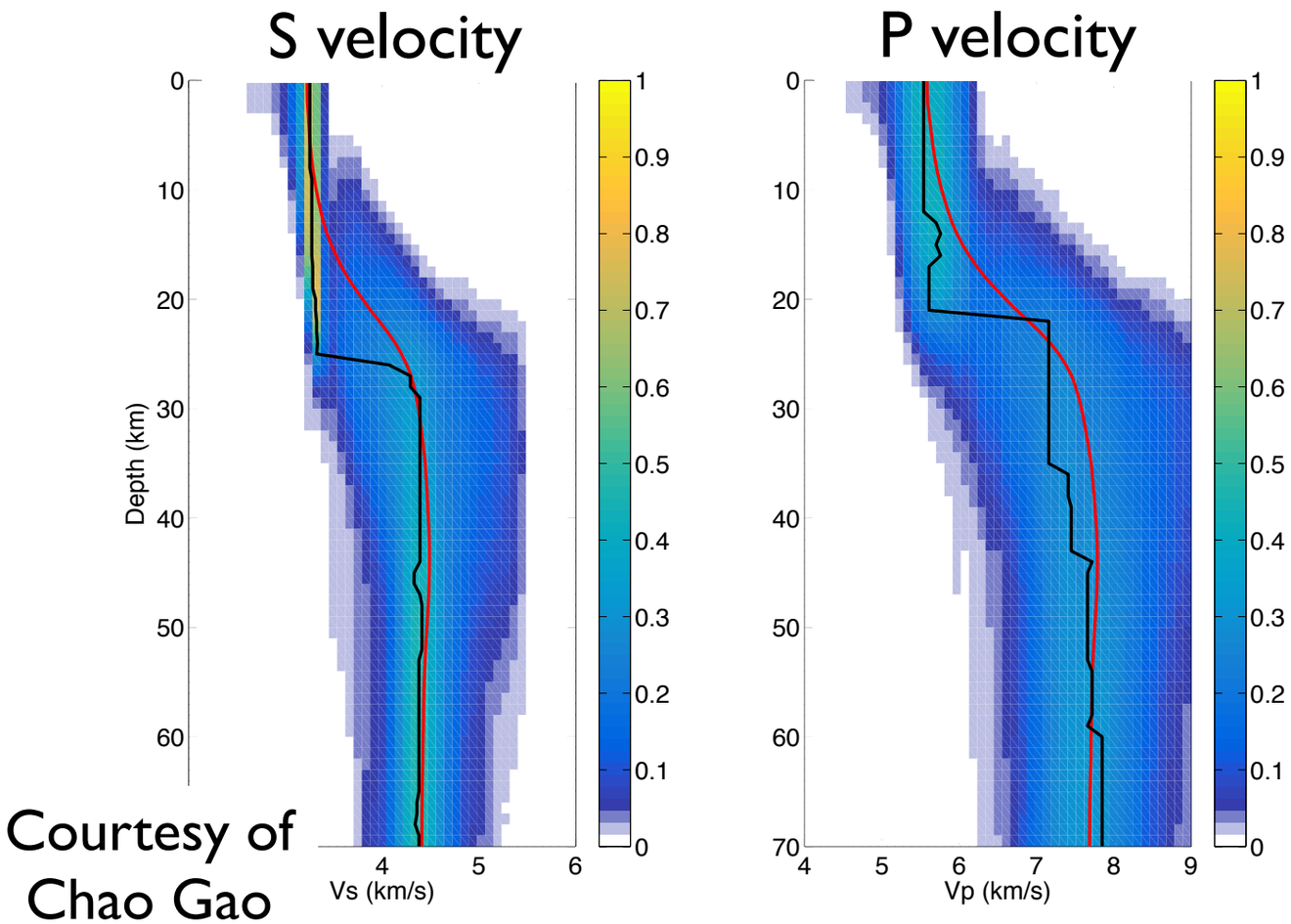
Receiver functions used



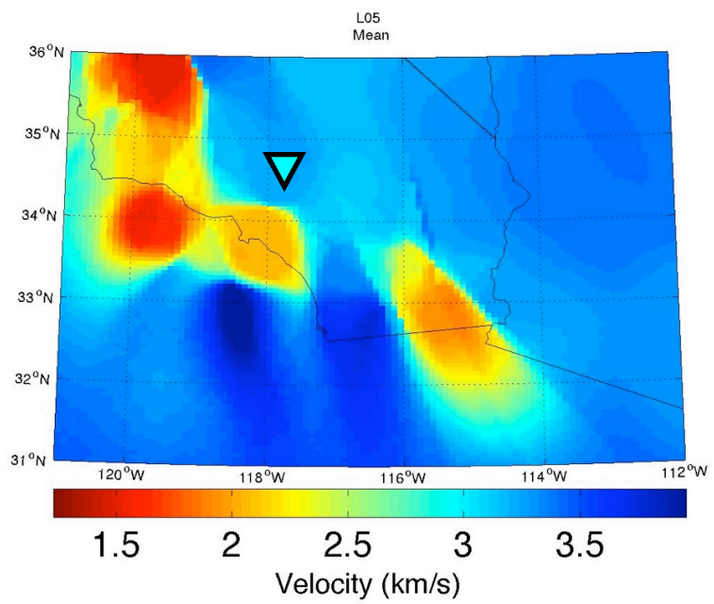
Forward modeled RFs



1-D surface wave inversion for station BBR



Courtesy of Chao Gao



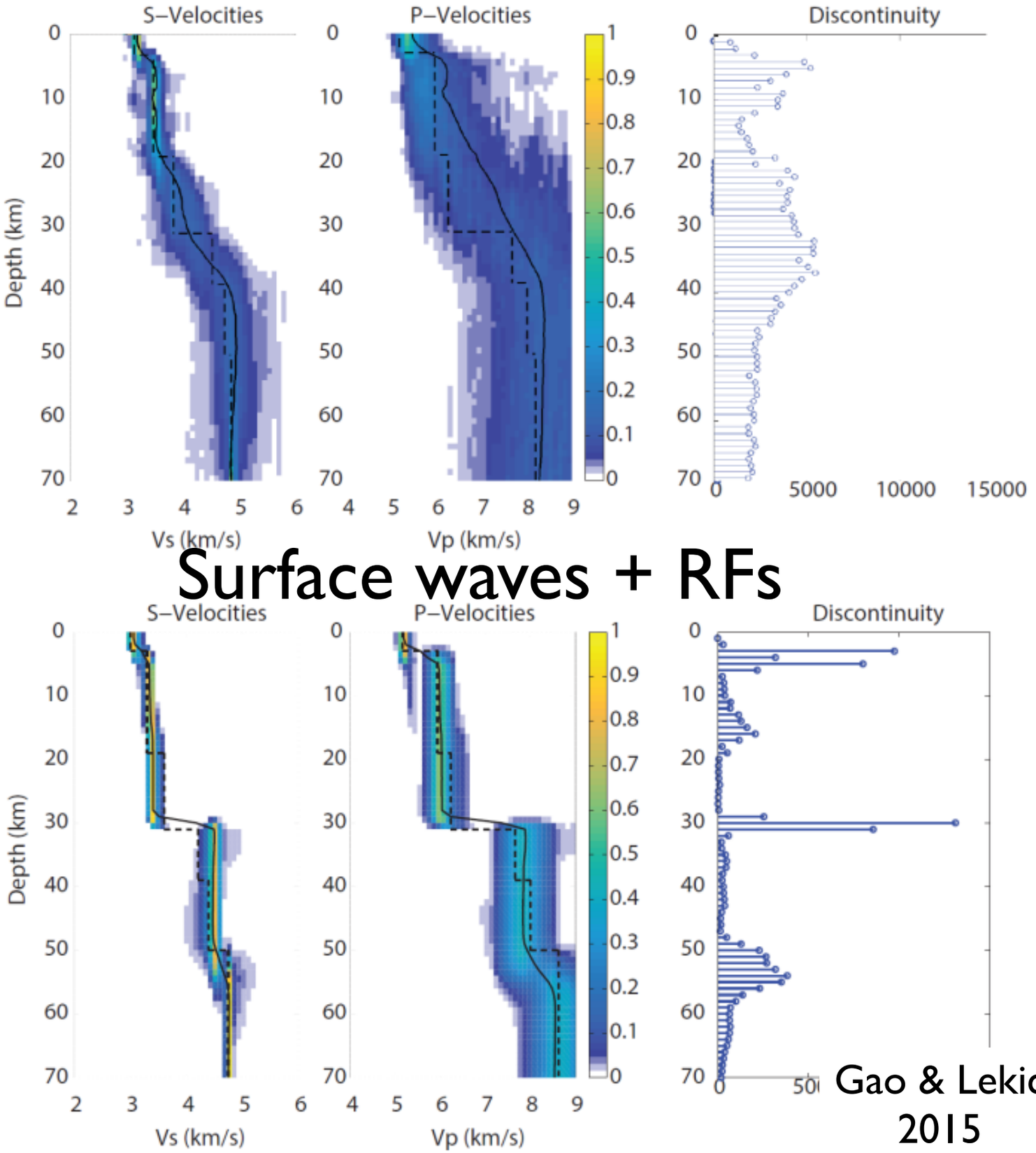
Phase velocity (5s Love)

Olugboji et al.

Vp/Vs Ratio?

- Receiver function inversion: constrain boundary depth given Vp/Vs
- Surface waves: constrain Vp and Vs given boundary depth
- Find model that satisfies both!

Surface waves alone



Surface waves + RFs

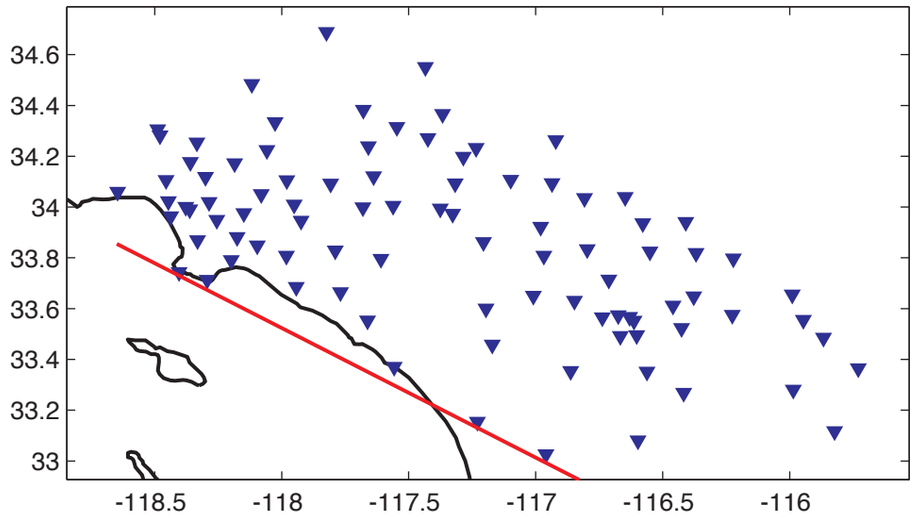
Gao & Lekic 2015

Probabilistic joint inversion of RFs and surface waves

- Test data fit with ~3 million models to determine statistics
- Reduce the tradeoff between Vp/Vs and depth of boundaries
- Estimate uncertainty in velocity structure, depth

Conclusions

- Desire for greater understanding of rifting processes —dominant rheology, mode of deformation—drives advances in seismic methods
- Full Waveform Inversion of receiver functions accounts for 3D structure and can image steep dips
- Probabilistic inversion of surface waves and receiver functions reduces (and estimates!) uncertainty in boundaries and Vp/Vs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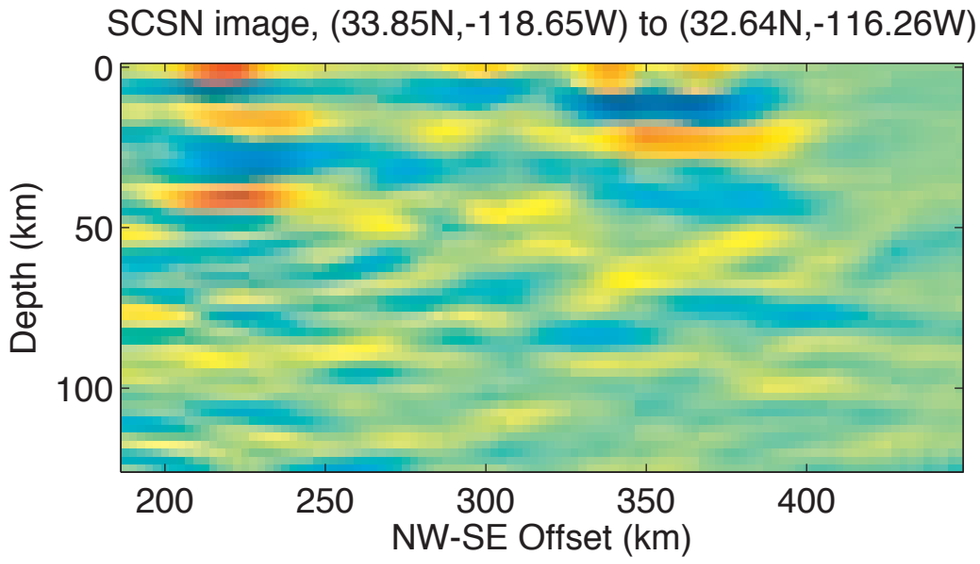
SCSN image, (33.85N,-118.65W) to (32.64N,-116.26W)
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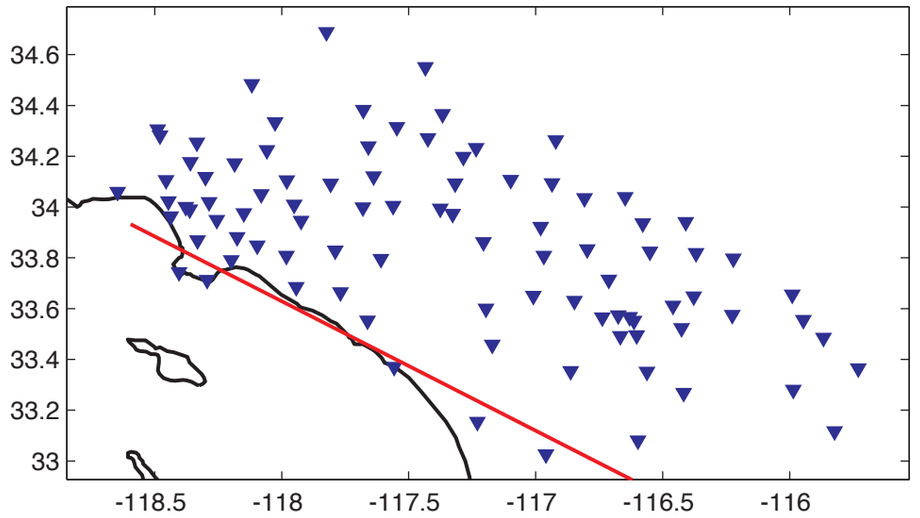
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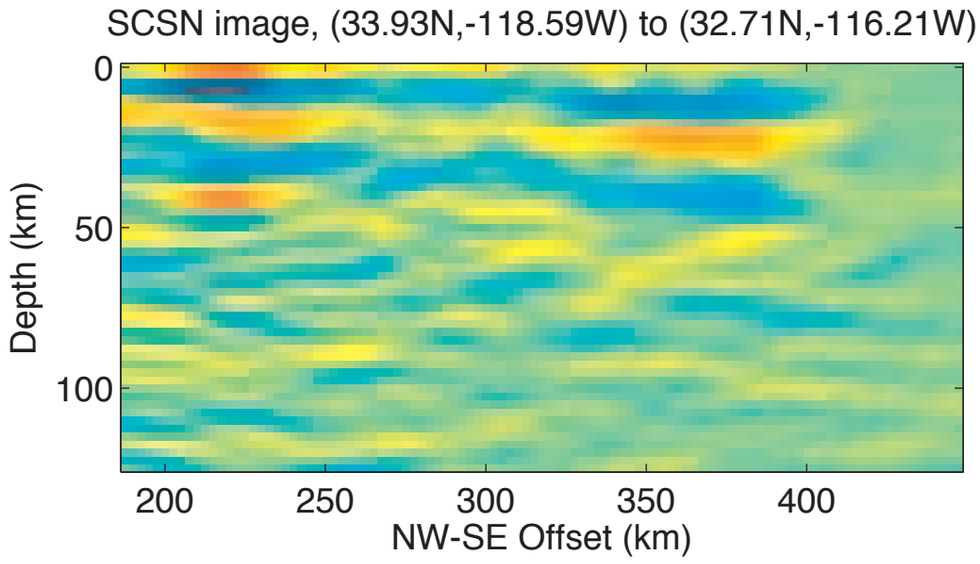
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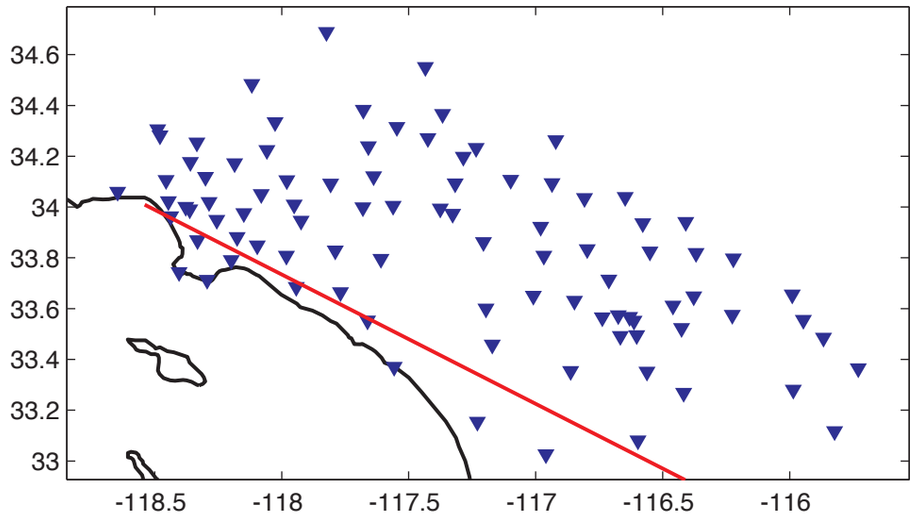
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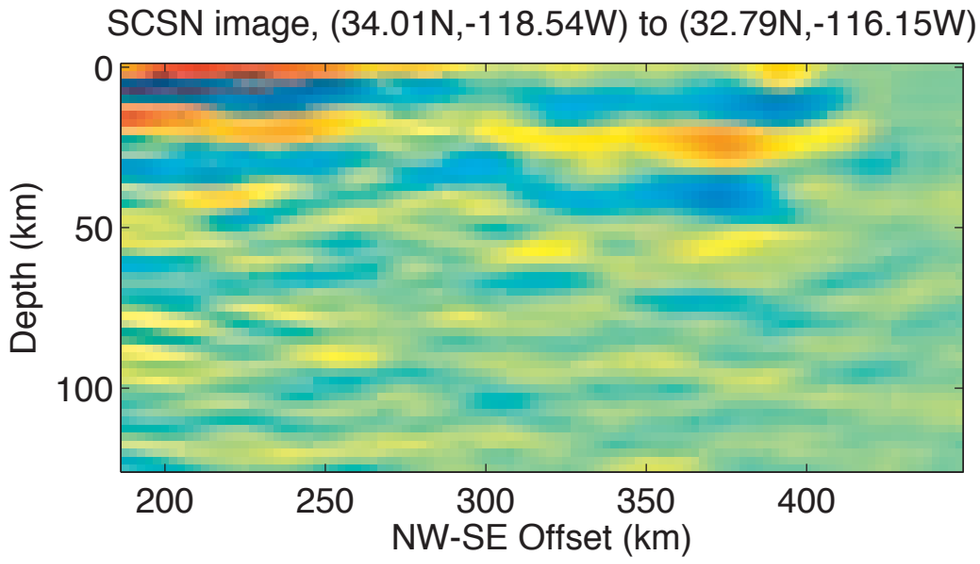
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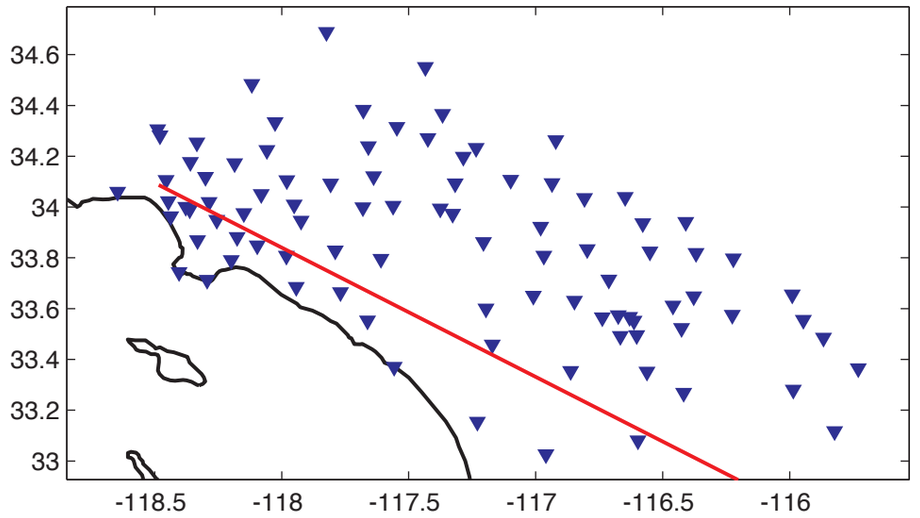
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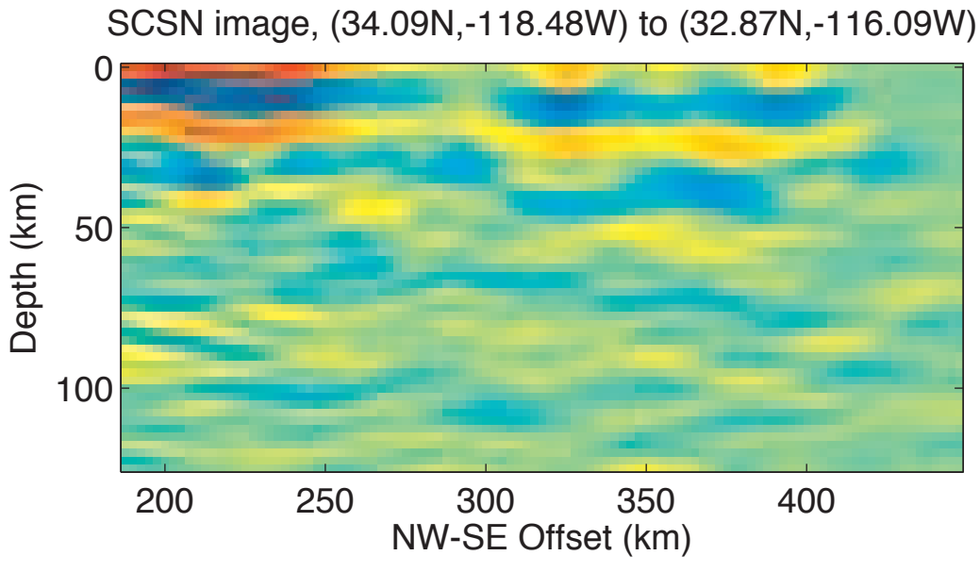
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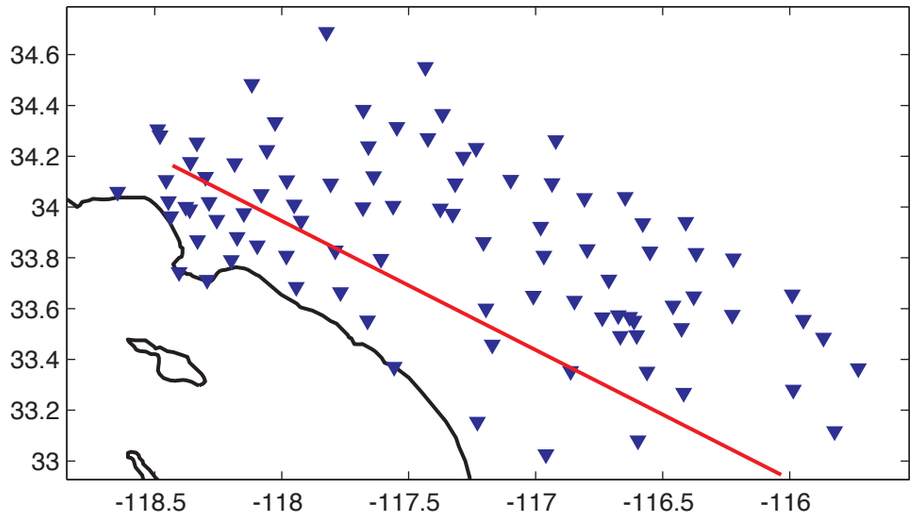
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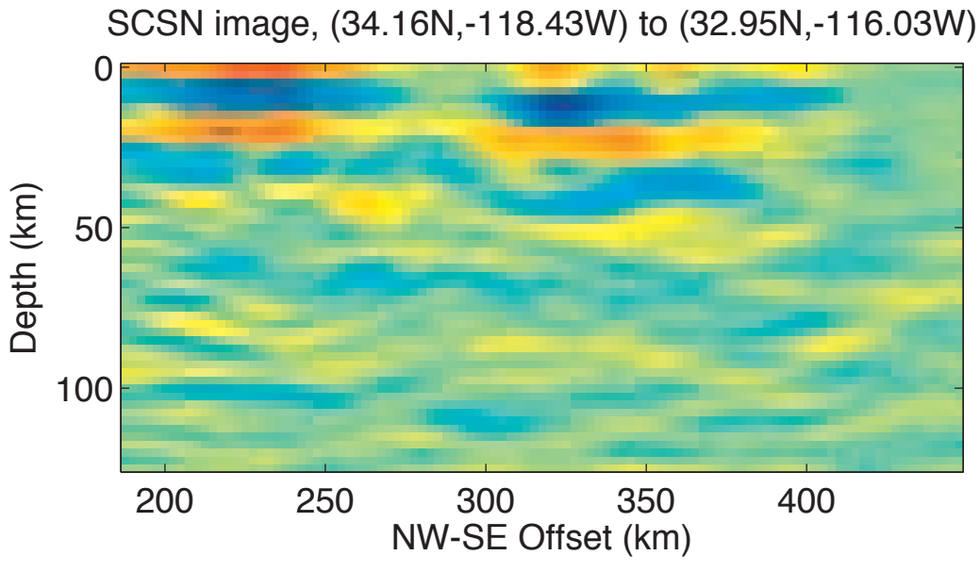
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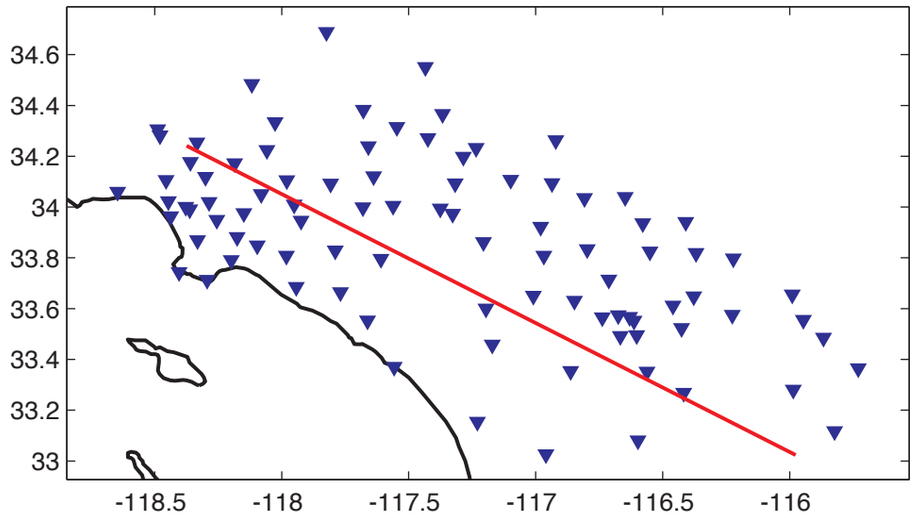
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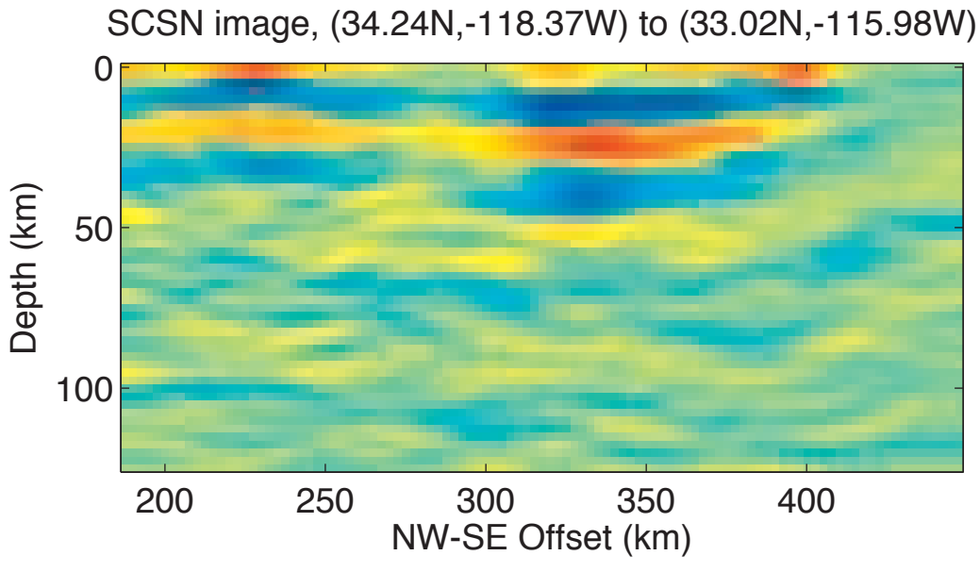
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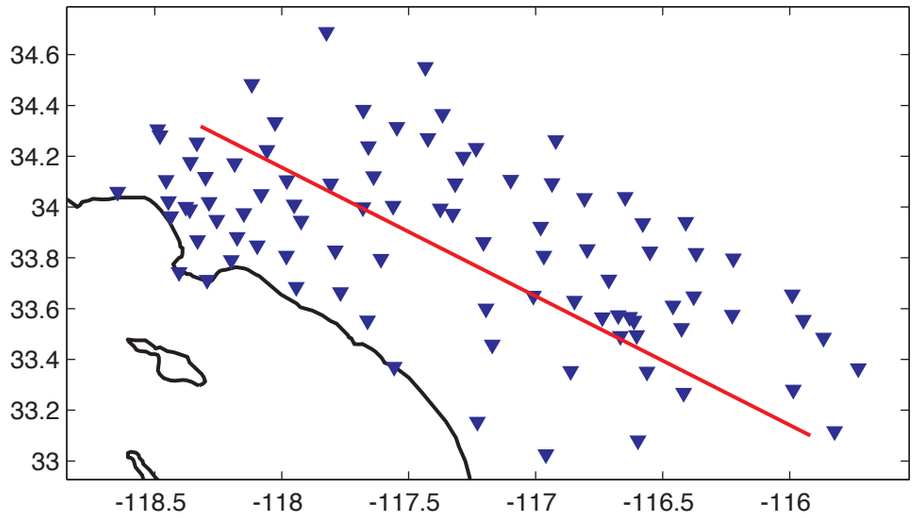
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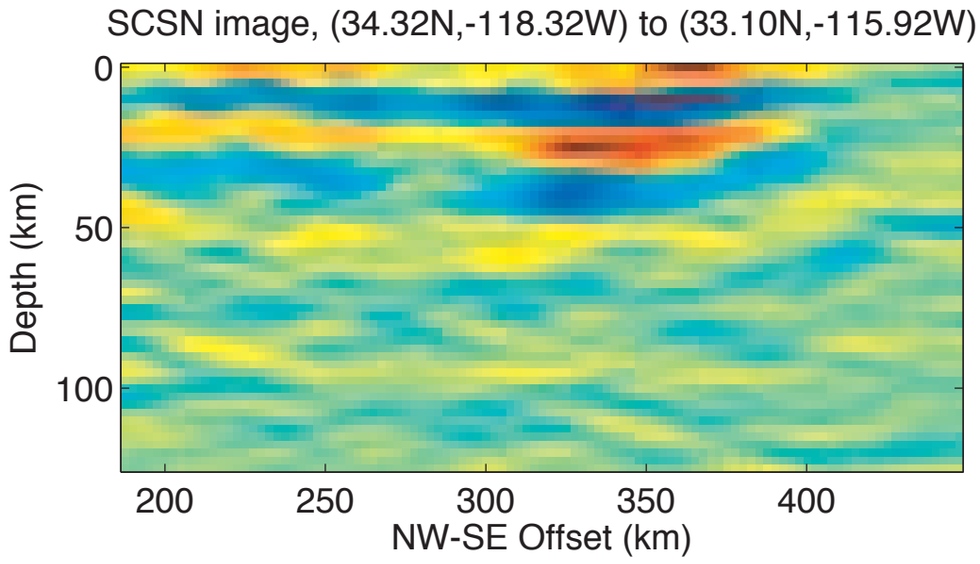
SCSN image, (34.32N,-118.32W) to (33.10N,-115.92W)
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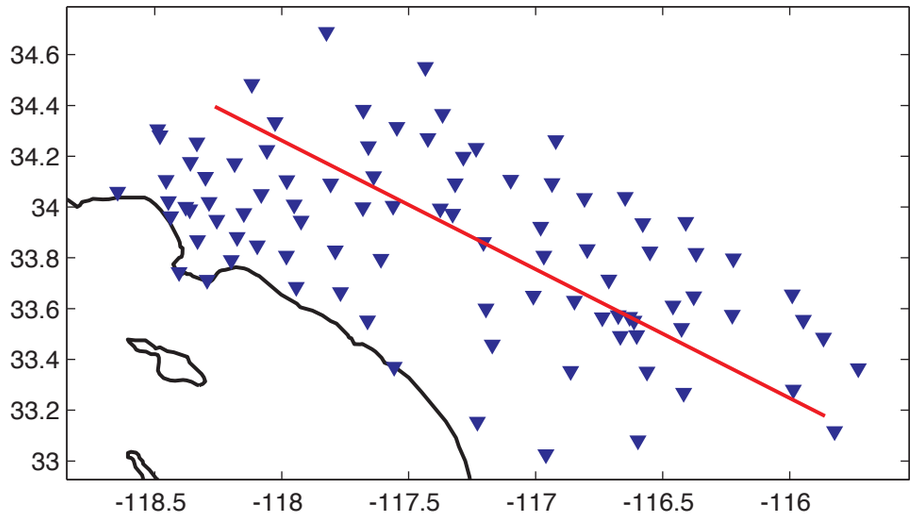
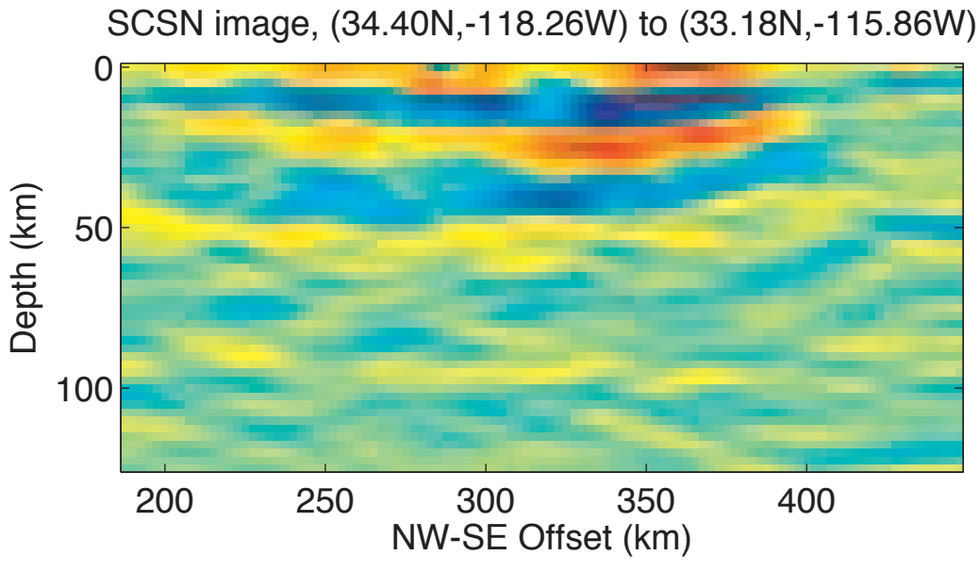
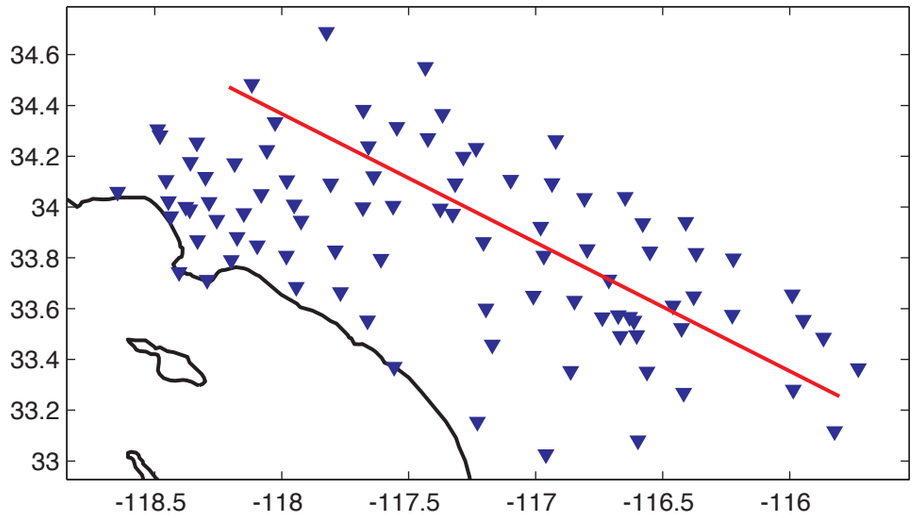
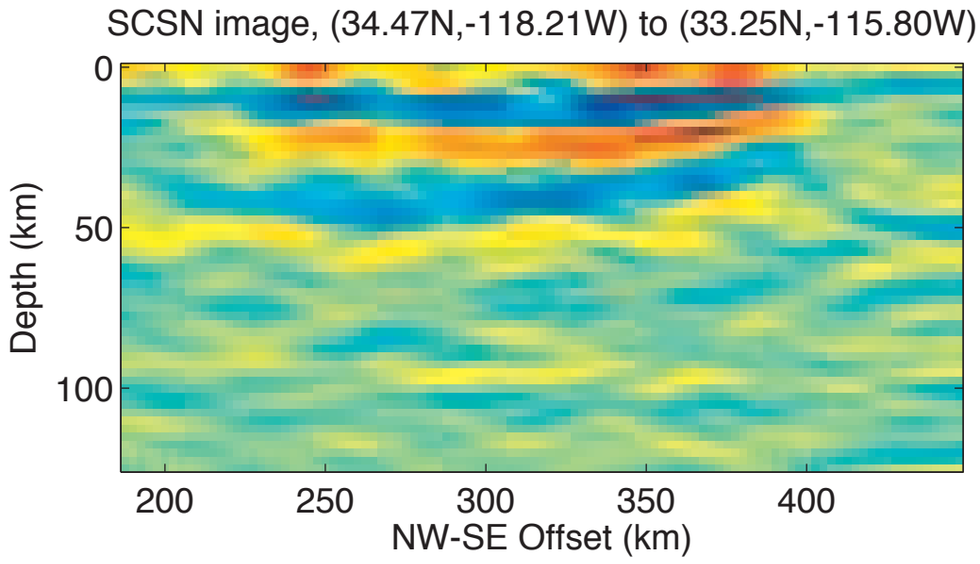
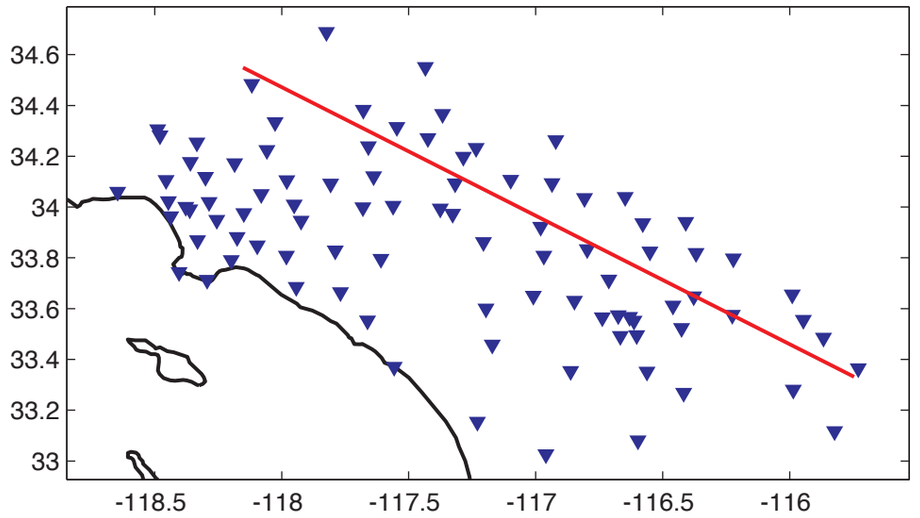
400
NW-SE Offset (km)

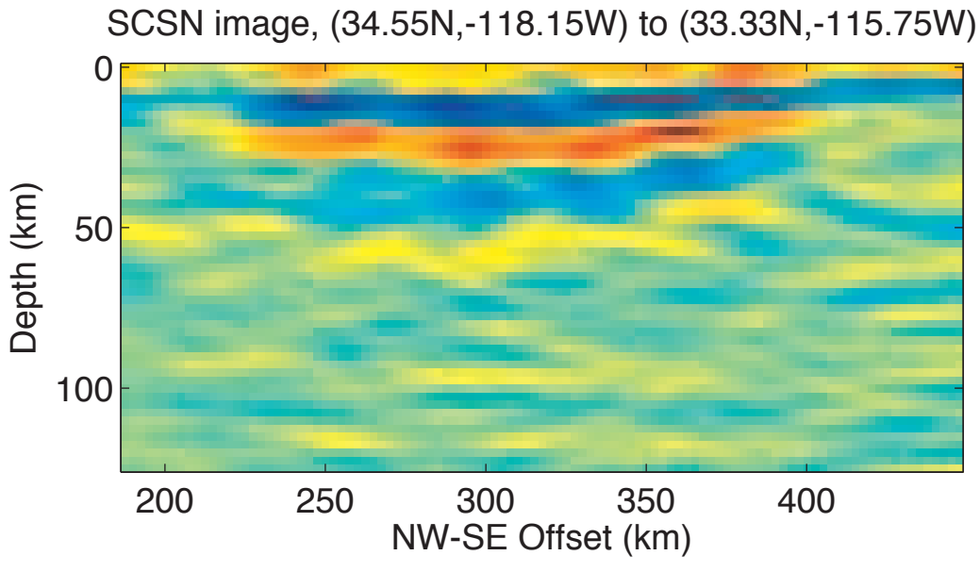

34.6
34.4
34.2
34
33.8
33.6
33.4
33.2
33
-118.5
-118
-117.5
-117
-116.5
-116

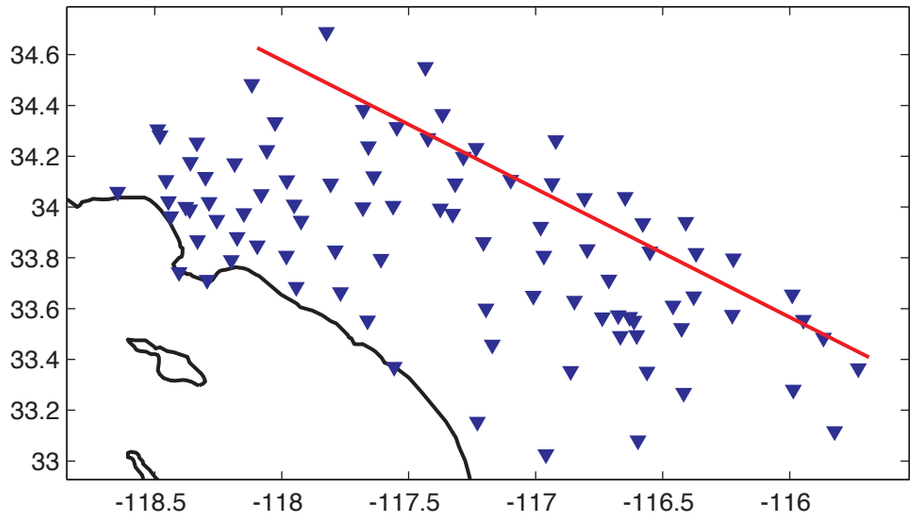

SCSN image, (34.40N,-118.26W) to (33.18N,-115.86W)
0
50
100
Depth (km)
200
250
300
350
400
NW-SE Offset (km)

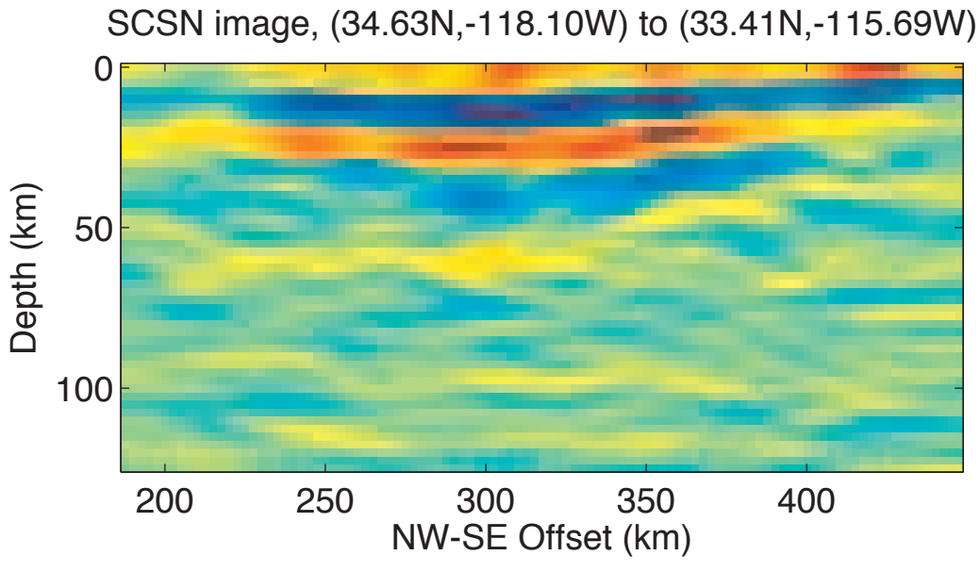

34.6
34.4
34.2
34
33.8
33.6
33.4
33.2
33
-118.5
-118
-117.5
-117
-116.5
-116

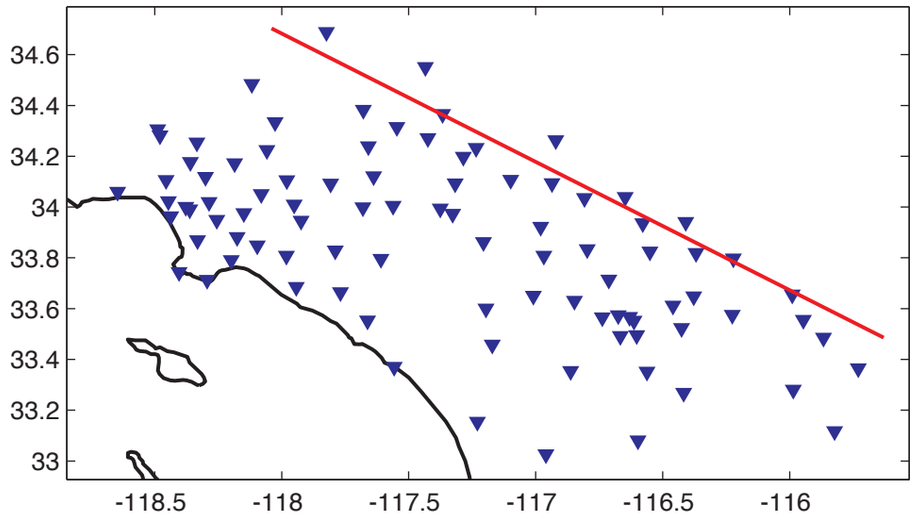

SCSN image, (34.47N,-118.21W) to (33.25N,-115.80W)
0
50
100
Depth (km)
200
250
300
350
400
NW-SE Offset (km)

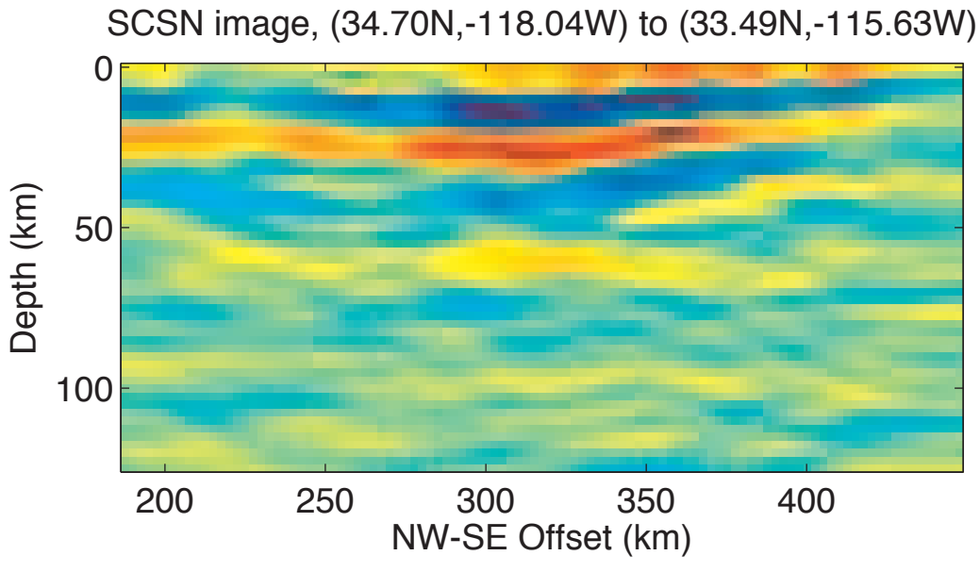

34.6
34.4
34.2
34
33.8
33.6
33.4
33.2
33
-118.5
-118
-117.5
-117
-116.5
-116


SCSN image, (34.55N,-118.15W) to (33.33N,-115.75W)
0
50
100
Depth (km)
200
250
300
350
400
NW-SE Offset (km)


34.6
34.4
34.2
34
33.8
33.6
33.4
33.2
33
-118.5
-118
-117.5
-117
-116.5
-116


SCSN image, (34.63N,-118.10W) to (33.41N,-115.69W)
0
50
100
Depth (km)
200
250
300
350
400
NW-SE Offset (km)


34.6
34.4
34.2
34
33.8
33.6
33.4
33.2
33
-118.5
-118
-117.5
-117
-116.5
-116


SCSN image, (34.70N,-118.04W) to (33.49N,-115.63W)
0
50
100
Depth (km)
200
250
300
350
400
NW-SE Offset (km)